WGMS 2009. Glacier Mass Balance Bulletin No. 10 (2006-2007)

Edited by: Haeberli, W ; Gärtner-Roer, I ; Hoelzle, M ; Paul, F ; Zemp, Michael

GLACIER MASS BALANCE BULLETIN

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A contribution to

the Global Terrestrial Network for Glaciers (GTN-G)
as part of the Global Terrestrial/Climate Observing System (GTOS/GCOS),

the Division of Early Warning and Assessment and the Global Environment Outlook
as part of the United Nations Environment Programme (DEWA and GEO, UNEP)

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Department of Geography
University of Zurich

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Cover Page

Brewster Glacier with Mt Brewster (2515 m a.s.l.) of the Southern Alps of New Zealand. Photo taken by A. Willsman (Glacier Snowline Survey, NIWA), 14 March 2008.

PREFACE

In-situ measurements of glacier mass balance constitute – and will continue to constitute – a key element in worldwide glacier monitoring as part of global climate-related observation systems. They improve our understanding of the involved processes relating to earth-atmosphere mass and energy fluxes and provide quantitative data at high (annual, seasonal) time resolution, which enables numerical models to be developed for climate-glacier relationships. Together with more numerous observations of glacier length change and air- and space-based spatial information on large glacier samples, this process understanding and quantitative modelling helps to bridge the gap between detailed local studies and global coverage. It also fosters realistic anticipation of possible further developments. The latter includes worst-case scenarios of drastic to even complete deglaciation in many mountain regions of the world as early as the next few decades. On a century time scale, changes in glaciers and ice caps are an easily recognized reflection of rapid if not accelerating changes in the energy balance of the earth's surface and, hence, are also among the most striking indicators in nature of global climate change. The general losses in length, area, thickness and volume of firn and ice can be visually detected and qualitatively understood by everyone. Numeric values and comprehensive analysis, however, must be provided by advanced science: while the initial phases following the cold centuries of the Little Ice Age were most probably related to effects from natural climate variability, anthropogenic influences have increased over the past decades to such an extent that – for the first time in history – continued shrinking of glaciers and ice caps may have become primarily forced by human impacts on the atmosphere.

International assessments such as the periodical reports of the Intergovernmental Panel on Climate Change (IPCC), the Cryosphere Theme Report of the WMO Integrated Global Observing Strategy (IGOS 2007) or various GCOS/GTOS reports (for instance, the implementation plan for the Global Observing System for Climate in support of the UNFCCC; GCOS 2009) clearly recognize glacier changes as high-confidence climate indicators and as a valuable element in early detection strategies. The report on «Global glacier changes – facts and figures» recently published by WGMS under the auspices of UNEP (WGMS 2008) presents a corresponding overview and detailed background information. Glacier changes in the perspective of global cryosphere evolution is treated in the «Global outlook for ice and snow » issued by UNEP (2007).

In order to further document the evolution and to clarify the physical processes and relationships involved, the World Glacier Monitoring Service (WGMS) of the International Association for the Cryospheric Sciences (IACS/IUGG) as one of the permanent services of the World Data System within the International Council of Science (WDS/ICSU) collects and publishes standardized glacier data. This long-term activity is a contribution to the Global Climate/Terrestrial Observing Systems (GCOS/GTOS), to the Division of Early Warning and Assessment and the Global Environment Outlook as part of the United Nations Environment Programme (DEWA and GEO, UNEP), as well as to the International Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organisation (UNESCO). In close cooperation with the Global Land Ice Measurement from Space (GLIMS) initiative and the National Snow and Ice Data Center (NSIDC) at Boulder, Colorado, an integrated and multi-level strategy within the Global Terrestrial Network for Glaciers (GTN-G) of GTOS is used to combine in-situ observations with remotely sensed data, process understanding with global coverage, and traditional measurements with new technologies. This approach, the Global Hierarchical Observing Strategy (GHOST), applies observations in a system of tiers. Tier 2 includes detailed glacier mass balance measurements within major climatic zones for improved process understanding and calibration of numerical models. Tier 3 uses cost-saving methodologies to determine regional glacier volume change within major mountain systems. The mass balance data compilation of the World Glacier Monitoring Service – a network of, at present, about 110 glaciers in 24 countries/regions, representing tiers 2 and 3 – is published in the form of the bi-annual Glacier Mass Balance Bulletin as well as annually in electronic form. Such a sample of glaciers provides information on presently observed rates of change in glacier mass as well as their regional distribution patterns and acceleration trends as an independent climate proxy.

The publication of standardized glacier mass balance data in the Glacier Mass Balance Bulletin is restricted to measurements which are based on the direct glaciological method and requested to be compared, and if necessary, adjusted to geodetic or photogrammetric surveys repeated at about decadal time intervals. In accordance with an agreement made with the international organizations and countries involved, preliminary glacier mass balance values are made available one year after the end of the measurement period on the WGMS homepage (www.wgms.ch). This internet homepage also contains former issues of and the present Glacier Mass Balance Bulletin, as well as explanations of the monitoring strategy. The following series of reports on the variations of glaciers in time and space has already been published by the WGMS and its predecessor, the Permanent Service on the Fluctuations of Glaciers (PSFG):

- Fluctuations of Glaciers 1959–1965 (Vol. 1, P. Kasser)
- Fluctuations of Glaciers 1965–1970 (Vol. 2, P. Kasser)
- Fluctuations of Glaciers 1970–1975 (Vol. 3, F. Müller)
- Fluctuations of Glaciers 1975–1980 (Vol. 4, W. Haeberli)
- Fluctuations of Glaciers 1980–1985 (Vol. 5, W. Haeberli and P. Müller)
- Fluctuations of Glaciers 1985–1990 (Vol. 6, W. Haeberli and M. Hoelzle)
- Fluctuations of Glaciers 1990–1995 (Vol. 7, W. Haeberli, M. Hoelzle, S. Suter and R. Frauenfelder)
- Fluctuations of Glaciers 1995–2000 (Vol. 8, W. Haeberli, M. Zemp, R. Frauenfelder, M. Hoelzle and A. Kääb)
- Fluctuations of Glaciers 2000–2005 (Vol. 9, W. Haeberli, M. Zemp, A. Kääb, F. Paul and M. Hoelzle)
- World Glacier Inventory – Status 1988 (W. Haeberli, H. Bösch, K. Scherler, G. Østrem and C.C. Wallén)
- Glacier Mass Balance Bulletin No. 1, 1988–1989 (W. Haeberli and E. Herren)
- Glacier Mass Balance Bulletin No. 2, 1990–1991 (W. Haeberli, E. Herren and M. Hoelzle)
- Glacier Mass Balance Bulletin No. 3, 1992–1993 (W. Haeberli, M. Hoelzle and H. Bösch)
- Glacier Mass Balance Bulletin No. 4, 1994–1995 (W. Haeberli, M. Hoelzle and S. Suter)
- Glacier Mass Balance Bulletin No. 5, 1996–1997 (W. Haeberli, M. Hoelzle and R. Frauenfelder)
- Glacier Mass Balance Bulletin No. 6, 1998–1999 (W. Haeberli, R. Frauenfelder and M. Hoelzle)
- Glacier Mass Balance Bulletin No. 7, 2000–2001 (W. Haeberli, R. Frauenfelder, M. Hoelzle and M. Zemp)
- Glacier Mass Balance Bulletin No. 8, 2002–2003 (W. Haeberli, J. Noetzli, M. Zemp, S. Baumann, R. Frauenfelder and M. Hoelzle)
- Glacier Mass Balance Bulletin No. 9, 2004–2005 (W. Haeberli, M. Hoelzle and M. Zemp)

The present Glacier Mass Balance Bulletin reporting the results from the balance years 2005/2006 and 2006/2007 is the tenth issue in a long-term series of publications. It is designed to speed up and facilitate access to information concerning glacier mass balances by reporting measured values from selected reference glaciers at 2-year intervals. The results of glacier mass balance measurements are made more easily understandable for non-specialists through the use of graphic illustrations in addition to numerical data. The Glacier Mass Balance Bulletin complements the publication series 'Fluctuations of Glaciers', where the full collection of digital data, including geodetic volume changes and the more numerous observations of glacier length variation, can be found. It should also be kept in mind that this fast and somewhat preliminary reporting of mass balance measurements may require slight correction and updating at a later time. Correspondingly corrected and updated information can be found in the Fluctuations of Glaciers series and are available in digital format from the WGMS.

Special thanks are extended to all those who have helped to build up the database which, despite its limitations, nevertheless remains an irreplaceable treasure of international snow and ice research, readily available to the scientific community as well as to a vast public.

Zurich, 2009

Wilfried Haeberli
Director, World Glacier Monitoring Service

TABLE OF CONTENTS

1 INTRODUCTION

The Glacier Mass Balance Bulletin reports on two main categories of data: basic information and detailed information. Basic information on specific net balance, cumulative specific balance, accumulation area ratio and equilibrium line altitude is given for 111 glaciers. Such information provides a regional overview. Additionally, detailed information such as balance maps, balance/altitude diagrams, relationships between accumulation area ratios, equilibrium line altitudes and balance, as well as a short explanatory text with a photograph is presented for 16 glaciers. These ones were chosen because they had a long and complete series of direct glaciological measurements taken over many years. These long time series, based on high density networks of stakes and firn pits, are especially valuable for analyzing processes of mass and energy exchange at glacier/atmosphere interfaces and, hence, for interpreting climate/glacier relationships. In order to provide broader-based information on glaciers from all regions worldwide, additional selected glaciers with shorter measurement series have been included.

1.1 GENERAL INFORMATION ON THE OBSERVED GLACIERS

The glaciers for which data is reported in the present bulletin are listed below (Table 1.1, Figure 1.1). Additionally, 20 glaciers with long measurement series of 15 years and more are listed.

Table 1.1: General geographic information on the 111 glaciers for which basic information for the years 2006 and/or 2007 is reported. Additionally, 20 glaciers with long measument series of 15 or more years are listed.

No.	Glacier Name[1)]	1st/last survey[2)]	Country	Location	Coordinates[3)]	
1	Bahía del Diablo	2002/2007	Antarctica	Antarctic Peninsula	63.82 S	57.43 W
2	Martial Este	2001/2007	Argentina	Andes Fueguinos	54.78 S	68.40 W
3	Filleckkees	1964/1980	Austria	Eastern Alps	47.13 N	12.60 E
4	Goldbergkees	2001/2007	Austria	Eastern Alps	47.03 N	12.47 E
5	Hintereisferner	1953/2007	Austria	Eastern Alps	46.80 N	10.77 E
6	Jamtalferner	1989/2007	Austria	Eastern Alps	46.87 N	10.17 E
7	Kesselwandferner	1953/2007	Austria	Eastern Alps	46.83 N	10.79 E
8	Kleinfleisskees	2001/2007	Austria	Eastern Alps	47.05 N	12.95 E
9	Pasterzenkees	2005/2007	Austria	Eastern Alps	47.10 N	12.70 E
10	Sonnblickkees	1959/2007	Austria	Eastern Alps	47.13 N	12.60 E
11	Vernagtferner	1965/2007	Austria	Eastern Alps	46.88 N	10.82 E
12	Wurtenkees	1983/2007	Austria	Eastern Alps	47.04 N	13.01 E
13	Chacaltaya	1992/2007	Bolivia	Tropical Andes	16.35 S	68.12 W
14	Charquini Sur	2003/2007	Bolivia	Tropical Andes	16.17 S	68.09 W
15	Zongo	1992/2007	Bolivia	Tropical Andes	16.25 S	68.17 W
16	Baby Glacier	1960/2005	Canada	High Arctic	79.43 N	90.97 W
17	Devon Ice Cap NW	1961/2007	Canada	High Arctic	75.42 N	83.25 W
18	Helm	1975/2007	Canada	Coast Mountains	49.97 N	123.00 W
19	Meighen Ice Cap	1976/2007	Canada	High Arctic	79.95 N	99.13 W
20	Peyto	1966/2007	Canada	Rocky Mountains	51.67 N	116.53 W
21	Place	1965/2007	Canada	Coast Mountains	50.43 N	122.6 W
22	Sentinel	1966/1989	Canada	Coast Mountains	49.90 N	122.98 W
23	White	1960/2007	Canada	High Arctic	79.45 N	90.67 W

No.	Glacier Name[1)]	1st/last survey[2)]	Country	Location	Coordinates[3)]	
24	Echaurren Norte	1976/2007	Chile	Central Andes	33.58 S	70.13 W
25	Urumqihe S.No.1	1959/2007	China	Tien Shan	43.08 N	86.82 E
	Urumqihe E-Branch	1988/2007	China	Tien Shan	43.08 N	86.82 E
	Urumqihe W-Branch	1988/2007	China	Tien Shan	43.08 N	86.82 E
26	La Conejera	2006/2007	Colombia	Cordillera Central	4.48 N	75.22 W
27	Ritacuba Negro	2007/2007	Colombia	Cordillera Oriental	6.45 N	72.3 W
28	Antizana 15 Alpha	1995/2007	Ecuador	Eastern Cordillera	0.47 S	78.15 W
29	Argentière	1976/2007	France	Western Alps	45.95 N	6.98 E
30	Gebroulaz	1995/2007	France	Western Alps	45.30 N	6.63 E
31	Ossoue	2002/2007	France	Pyrenees	42.77 N	0.14 W
32	Saint Sorlin	1957/2007	France	Western Alps	45.17 N	6.15 E
33	Sarennes	1949/2007	France	Western Alps	45.14 N	6.14 E
34	Mittivakkat	2006/2006	Greenland	South-eastern Greenland	65.67 N	37.83 W
35	Brúarjökull	1994/2007	Iceland	Eastern Iceland	64.67 N	16.17 W
36	Dyngjujökull	1994/2007	Iceland	Central Northern Iceland	64.67 N	17.00 W
37	Eyjabakkajökull	1994/2007	Iceland	Eastern Iceland	64.65 N	15.58 W
38	Hofsjökull E	1989/2005	Iceland	Central Iceland	64.80 N	18.58 W
39	Hofsjökull N	1988/2006	Iceland	Central Iceland	64.95 N	18.92 W
40	Hofsjökull SW	1990/2006	Iceland	Central Iceland	64.72 N	19.05 W
41	Koeldukvislarjökull	1995/2007	Iceland	Central Iceland	64.58 N	17.83 W
42	Langjökull S. Dome	1997/2007	Iceland	Central Iceland	64.62 N	20.30 W
43	Tungnaárjökull	1994/2007	Iceland	Central Iceland	64.32 N	18.07 W
44	Chhota Shigri	2003/2006	India	Western Himalaya	32.20 N	77.50 E
45	Hamtah	2001/2006	India	Himachal Pradesh	32.24 N	77.37 E
46	Calderone	2001/2007	Italy	Apennin	42.47 N	13.62 E
47	Caresèr[4)]	1967/2007	Italy	Central Alps	46.45 N	10.70 E
	Caresèr orientale[4)]	2006/2007	Italy	Central Alps	46.45 N	10.70 E
	Caresèr occidentale[4)]	2006/2007	Italy	Central Alps	46.45 N	10.69 E
48	Ciardoney	1992/2007	Italy	Western Alps	45.52 N	7.40 E
49	Fontana Bianca	1984/2007	Italy	Central Alps	46.48 N	10.77 E
50	Lunga (Vedretta)	2004/2007	Italy	Central Alps	46.47 N	10.62 E
51	Malavalle	2002/2007	Italy	Central Alps	46.95 N	11.12 E
52	Pendente	1996/2007	Italy	Central Alps	46.96 N	11.23 E
53	Hamaguri Yuki[5)]	1981/2007	Japan	Northern Japan Alps	36.60 N	137.62 E
54	Igly Tuyuksu	1976/1990	Kazakhstan	Tien-Shan	43.00 N	77.10 E
55	Manshuk Mametova	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
56	Mayakovskiy	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
57	Molodezhniy	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
58	Ordzhonikidze	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
59	Partizan	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
60	Shumskiy	1967/1991	Kazakhstan	Dzhungarskiy	45.08 N	80.23 E
61	Ts. Tuyuksuyskiy	1957/2007	Kazakhstan	Tien Shan	43.05 N	77.08 E

No.	Glacier Name[1)]	1st/last survey[2)]	Country	Location	Coordinates[3)]	
62	Visyachiy-1-2	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
63	Zoya Kosmodemyansk.	1976/1990	Kazakhstan	Tien Shan	43.00 N	77.10 E
64	Golubin	1969/1994	Kirghizstan	Tien-Shan	42.47 N	74.50 E
65	Kara-Batkak	1957/1998	Kirghizstan	Tien-Shan	42.10 N	78.30 E
66	Lewis	1979/1996	Kenya	East Africa	0.15 S	37.30 E
67	Brewster	2005/2007	New Zealand	Tititea Mt Aspiring NP	44.08 S	169.44 E
68	Ålfotbreen	1963/2007	Norway	Western Norway	61.75 N	5.65 E
69	Austdalsbreen	1987/2007	Norway	Western Norway	61.80 N	7.35 E
70	Austre Brøggerbreen	1967/2007	Norway	Spitsbergen	78.88 N	11.83 E
71	Blomstølskardsbreen	2007/2007	Norway	South-western Norway	60.00 N	6.40 E
72	Breidablikkbrea	1963/2007	Norway	South-western Norway	60.10 N	6.40 E
73	Elisebreen	2006/2007	Norway	Spitsbergen	78.64 N	12.25 E
74	Engabreen	1970/2007	Norway	Northern Norway	66.65 N	13.85 E
75	Gråfjellsbrea	1964/2007	Norway	South-western Norway	60.10 N	6.40 E
76	Gråsubreen	1962/2007	Norway	Southern Norway	61.65 N	8.60 E
77	Hansbreen	1989/2007	Norway	Spitsbergen	77.08 N	15.67 E
78	Hansebreen	1986/2007	Norway	Western Norway	61.75 N	5.68 E
79	Hardangerjøkulen	1963/2007	Norway	Central Norway	60.53 N	7.37 E
80	Hellstugubreen	1962/2007	Norway	Southern Norway	61.57 N	8.43 E
81	Irenebreen	2002/2007	Norway	Spitsbergen	78.65 N	12.10 E
82	Kongsvegen	1987/2007	Norway	Spitsbergen	78.80 N	12.98 E
83	Langfjordjøkelen	1989/2007	Norway	Northern Norway	70.12 N	21.77 E
84	Midtre Lovénbreen	1968/2007	Norway	Spitsbergen	78.88 N	12.07 E
85	Nigardsbreen	1962/2007	Norway	Western Norway	61.72 N	7.13 E
86	Storbreen	1949/2007	Norway	Central Norway	61.57 N	8.13 E
87	Svelgjabreen	2007/2007	Norway	South-western Norway	60.00 N	6.40 E
88	Waldemarbreen	1995/2007	Norway	Spitsbergen	78.67 N	12.00 E
89	Artesonraju	2005/2007	Peru	Cordillera Blanca	8.95 S	77.62 W
90	Yanamarey	2005/2007	Peru	Cordillera Blanca	9.65 S	77.27 W
91	Abramov	1968/1998	Tadjikistan	Pamir Alai	39.63 N	71.60 E
92	Djankuat	1968/2007	Russia	Northern Caucasus	43.20 N	42.77 E
93	Garabashi	1984/2007	Russia	Northern Caucasus	43.30 N	42.47 E
94	Kozelskiy	1973/1997	Russia	Kamchatka	53.23 N	158.82 E
95	Leviy Aktru	1977/2007	Russia	Altay	50.08 N	87.72 E
96	Maliy Aktru	1962/2007	Russia	Altay	50.08 N	87.75 E
97	No. 125 (Vodopadniy)	1977/2007	Russia	Altay	50.10 N	87.70 E
98	Maladeta	1992/2007	Spain	South Pyrenees	42.65 N	0.64 E
99	Mårmaglaciären	1990/2007	Sweden	Northern Sweden	68.83 N	18.67 E
100	Rabots Glaciär	1982/2006	Sweden	Northern Sweden	67.90 N	18.55 E
101	Riukojietna	1986/2007	Sweden	Northern Sweden	68.08 N	18.08 E
102	Storglaciären	1946/2007	Sweden	Northern Sweden	67.90 N	18.57 E
103	Tarfalaglaciären	1986/2007	Sweden	Northern Sweden	67.93 N	18.65 E

No.	Glacier Name[1)]	1st/last survey[2)]	Country	Location	Coordinates[3)]	
104	Basòdino	1992/2007	Switzerland	Western Alps	46.42 N	8.48 E
105	Findelen	2005/2007	Switzerland	Western Alps	46.00 N	7.87 E
106	Gries	1962/2007	Switzerland	Western Alps	46.44 N	8.34 E
107	Limmern	1948/1984	Switzerland	Western Alps	46.82 N	8.98 E
108	Plattalva	1948/1984	Switzerland	Western Alps	46.83 N	8.98 E
109	Silvretta	1960/2007	Switzerland	Eastern Alps	46.85 N	10.08 E
110	Blue Glacier	1956/1999	USA	Washington	47.82 N	123.68 W
111	Columbia (2057)	1984/2007	USA	North Cascades	47.97 N	121.35 W
112	Daniels	1984/2007	USA	North Cascades	47.57 N	121.17 W
113	Easton	1990/2007	USA	North Cascades	48.75 N	120.83 W
114	Emmons	2003/2007	USA	Mt Rainier	46.85 N	121.72 W
115	Foss	1984/2007	USA	North Cascades	47.55 N	121.20 W
116	Gulkana	1966/2007	USA	Alaska Range	63.25 N	145.42 W
117	Ice Worm	1984/2007	USA	North Cascades	47.55 N	121.17 W
118	Lemon Creek	1953/2007	USA	Coast Mountains	58.38 N	134.40 W
119	Lower Curtis	1984/2007	USA	North Cascades	48.83 N	121.62 W
120	Lynch	1984/2007	USA	North Cascades	47.57 N	121.18 W
121	Nisqually	2003/2007	USA	Mt Rainier	46.82 N	121.74 W
122	Noisy Creek	1993/2007	USA	Washington	48.67 N	121.53 W
123	North Klawatti	1993/2007	USA	Washington	48.57 N	121.12 W
124	Rainbow	1984/2007	USA	North Cascades	48.80 N	121.77 W
125	Sandalee	1995/2007	USA	Washington	48.42 N	120.80 W
126	Sholes	1990/2007	USA	North Cascades	48.80 N	121.78 W
127	Silver	1993/2007	USA	Washington	48.98 N	121.25 W
128	South Cascade	1953/2007	USA	North Cascades	48.37 N	121.05 W
129	Taku	1946/2007	USA	Coast Mountains	58.55 N	134.13 W
130	Wolverine	1966/2007	USA	Kenai Mtns	60.40 N	148.92 W
131	Yawning	1984/2007	USA	North Cascades	48.45 N	121.03 W

1) Countries and glaciers are listed in alphabetical order
2) Years of first and most recent survey available to the WGMS
3) Coordinates in decimal notation
4) In 2005, Caresèr broke into two parts: Caresèr Orientale and Caresèr Occidentale.
5) Perennial snowfield or glacieret

1.2 GLOBAL OVERVIEW MAP

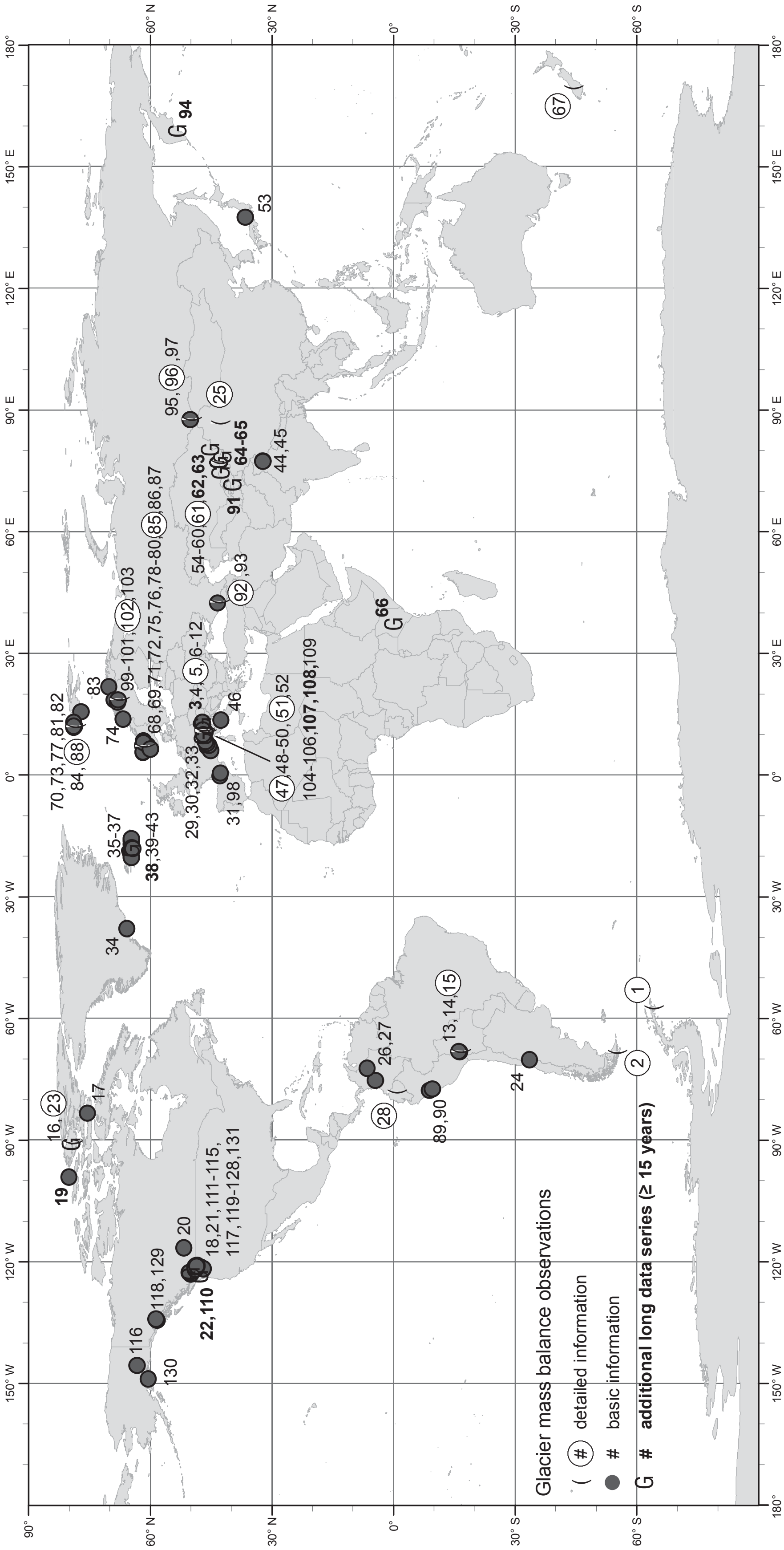


Figure 1.1: Location of the 111 glaciers for which basic information is reported. Additionally, 20 glaciers with interrupted long-term measument series are marked (i.e., 15 or more years).

2 BASIC INFORMATION

Specific net balance (b), equilibrium line altitude (ELA) and accumulation area ratio (AAR) from the balance years 2005/06 and 2006/07 are presented in Part 2.1. ELAs above and below the glacier elevation range are marked with > and <, respectively. In these cases, the ELA value given is supposed to be the glacier max/min elevation. The AAR values are given as integer values only.

Values for ELA_0 and AAR_0 are also given. They represent the calculated ELA and AAR values for a zero net balance, i.e., a hypothetical steady state. All values since the beginning of mass balance measurement-taking were used for this calculation on each glacier. Minimum sample size for regression was defined as six ELA or AAR values. In extreme years some of the observed glaciers can become entirely ablation or accumulation areas. Corresponding AAR values of 0 or 100 % as well as ELA values outside the altitude range of the observed glaciers were excluded from the calculation of AAR_0 and ELA_0 values. For the glaciers with detailed information, the corresponding graphs (AAR and ELA vs. specific net balance) are given in Chapter 3.

The graphs in the second part present the development of cumulative specific net balance over the whole observation period for each glacier where three or more net balances were reported and the years 2005/06 or 2006/07 are included. For each country, the cumulative balances are plotted in a single graph. For countries with more than six glaciers, the cumulative balances were plotted in several graphs, which were split into groups of glaciers from the same region, similar glacier types or alphabetically separated groups. Some of the time series have data gaps and hence have to be interpreted with care. In these cases, the overall ice loss cannot be derived from the cumulative specific net balance graphs and has to be determined by other means, such as geodetic or photogrammetric methods. Generally, for glaciers with data gaps longer than one-fifth of the measurement time series, the cumulative balance has been plotted for the measurements taken after the most recent data gap only.

2.1 SUMMARY TABLE (NET BALANCE, ELA, ELA_0, AAR, AAR_0)

Name	Country	b06 [mm]	b07 [mm]	ELA06 [m a.s.l.]	ELA07 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR06 [%]	AAR07 [%]	AAR_0 [%]
Bahía del Diablo	Antarctica	− 580	− 80	445	360	366	31	49	48
Martial Este	Argentina	− 513	− 99	1096	1072	—	38	62	—
Goldbergkees	Austria	− 1077	− 1106	3020	3000	—	7	24	45
Hintereisferner	Austria	− 1516	− 1797	> 3750	> 3750	2922	11	0	66
Jamtalferner	Austria	− 1293	− 1438	> 3120	> 3120	2760	8	6	58
Kesselwandferner	Austria	− 617	− 837	3233	3280	3114	33	22	69
Kleinfleisskees	Austria	− 655	− 946	3070	3020	2856	10	23	70
Pasterzenkees	Austria	− 1232	− 1355	3000	3025	—	47	49	—
Sonnblickkees	Austria	− 621	− 2175	2860	2990	2740	29	2	59
Vernagtferner	Austria	− 882	− 966	3261	3281	3080	25	19	66
Wurtenkees	Austria	− 778	− 1200	3120	> 3150	2905	17	4	36
Chacaltaya	Bolivia	− 1199	− 1652	5383	> 5400	—	0	0	—
Charquini Sur	Bolivia	− 376	− 482	5132	5157	—	50	38	—
Zongo	Bolivia	− 197	− 173	5191	5271	5231	71	62	67

Name	Country	b06 [mm]	b07 [mm]	ELA06 [m a.s.l.]	ELA07 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR06 [%]	AAR07 [%]	AAR_0 [%]
Devon Ice Cap NW	Canada	− 242	− 291	1340	1296	1004	—	—	71 [1)]
Helm	Canada	− 2750	− 210	> 2150	2007	2000	0	12	37
Meighen Ice Cap	Canada	− 8	− 518	—	—	—	—	—	—
Peyto	Canada	− 1650	− 1850	3090	3010	2612	10	40	52
Place	Canada	− 1900	− 150	> 2610	2180	2085	0	26	49
White	Canada	− 93	− 818	1097	1347	910	61	25	71
Echaurren Norte	Chile	+ 560	− 130	—	—	—	—	—	—
Urumqihe S. No.1	China	− 774	− 642	4087	4074	4022	28	31	56
Urumqihe E-Branch	China	− 920	− 696	4086	4060	3949	19	28	65
Urumqihe W-Branch	China	− 506	− 542	4089	4100	4024	43	36	64
La Conejera	Colombia	− 1935	− 996	—	—	—	—	—	—
Ritacuba Negro	Colombia	—	− 2227	—	—	—	—	—	—
Antizana 15 Alpha	Ecuador	− 452	− 658	5150	5170	5045	54	53	70
Argentière	France	− 1420	− 590	—	—	—	—	—	—
Gebroulaz	France	− 1000	− 910	—	—	—	—	—	—
Ossoue	France	− 2710	− 1380	> 3200	> 3200	—	0	0	—
Saint Sorlin	France	− 1440	− 2250	—	—	2863	—	—	—
Sarennes	France	− 2380	− 2520	—	—	—	—	—	—
Mittivakkat	Greenland	− 590	—	—	—	—	—	—	—
Brúarjökull	Iceland	− 790	− 536	—	—	1183	—	—	60
Dyngjujökull	Iceland	− 353	+ 95	—	—	—	—	—	—
Eyjabakkajökull	Iceland	− 1425	− 636	—	—	1074	—	—	56
Hofsjökull N	Iceland	− 510	—	1325	—	1264	41	—	50
Hofsjökull SW	Iceland	− 610	—	1330	—	1266	50	—	46
Koeldukvislarjökull	Iceland	− 402	− 342	—	—	1289	—	—	60
Langjökull S. Dome	Iceland	− 1080	− 1412	—	—	975	—	—	57
Tungnaárjökull	Iceland	− 1569	− 997	—	—	1147	—	—	61
Chhota Shigri	India	− 1413	—	5185	—	—	29	—	—
Hamtah	India	− 790	—	—	—	—	12	—	—
Calderone	Italy	+ 1090	− 2320	< 2630	> 2830	—	100	0	—
Caresèr [2)]	Italy	− 2093	− 2745	> 3279	> 3279	3094	0	0	44
Caresèr orientale [2)]	Italy	− 2117	− 2769	> 3277	> 3277	—	0	0	—
Caresèr occidentale [2)]	Italy	− 1911	− 2558	> 3279	> 3279	—	0	0	—
Ciardoney	Italy	− 2099	− 1490	> 3150	> 3150	2977	0	0	57
Fontana Bianca	Italy	− 1753	− 1607	> 3355	> 3355	3255	0	0	55
Lunga (Vedretta)	Italy	− 1456	− 1616	3295	> 3390	—	10	0	—
Malavalle	Italy	− 1327	− 1338	3200	3224	2930	12	9	56
Pendente	Italy	− 1740	− 2154	> 3075	> 3075	2822	0	0	45
Hamaguri Yuki [3)]	Japan	+ 3289	− 609	—	—	—	—	—	—
Ts. Tuyuksuyskiy	Kazakhstan	− 969	− 915	3980	3885	3746	22	34	52
Brewster	New Zealand	+ 282	+ 297	1893	1899	—	72	67	—
Ålfotbreen	Norway	− 3190	+ 1270	> 1382	1000	1199	0	97	57
Austdalsbreen	Norway	− 2060	+ 180	> 1757	1405	1423	0	75	65
Austre Brøggerbreen	Norway	− 730	− 460	458	427	282	5	10	52
Blomstølskardsbreen	Norway	—	+ 1880	—	1230	—	—	89	—
Breidablikkbrea	Norway	− 2950	+ 360	> 1659	1410	1473	0	68	—
Elisebreen	Norway	− 726	− 542	398	392	—	40	40	—
Engabreen	Norway	− 1360	+ 1100	1325	1035	1157	37	84	60
Gråfjellsbrea	Norway	− 3150	+ 750	> 1659	1395	1456	0	80	—
Gråsubreen	Norway	− 2080	− 710	> 2290	2265	2080	0	1	41
Hansbreen	Norway	+ 93	− 4	300	330	301	61	54	55

Name	Country	b06 [mm]	b07 [mm]	ELA06 [m a.s.l.]	ELA07 [m a.s.l.]	ELA_0 [m a.s.l.]	AAR06 [%]	AAR07 [%]	AAR_0 [%]
Hansebreen	Norway	− 3980	+ 845	> 1327	1042	1158	0	89	56
Hardangerjøkulen	Norway	− 2220	+ 1170	> 1860	1570	1678	0	85	68
Hellstugubreen	Norway	− 2010	− 670	> 2210	1975	1838	0	25	58
Irenebreen	Norway	− 822	− 695	422	454	263	24	20	56
Kongsvegen	Norway	+ 20	− 90	530	555	537	46	39	48
Langfjordjøkelen	Norway	− 2410	− 810	> 1050	870	716	0	42	64
Midtre Lovénbreen	Norway	− 480	− 250	415	376	296	14	26	57
Nigardsbreen	Norway	− 1399	+ 1047	1850	1320	1558	4	91	60
Storbreen	Norway	− 2150	− 390	> 2100	1835	1717	0	30	59
Svelgjabreen	Norway	—	+ 1350	—	1205	—	—	78	—
Waldemarbreen	Norway	− 747	− 771	425	428	270	16	13	47
Artesonraju	Peru	− 1679	− 1522	—	—	—	—	—	—
Yanamarey	Peru	− 1712	− 1532	4888	4868	—	27	36	—
Djankuat	Russia	− 800	− 2010	3290	3500	3189	42	16	56
Garabashi	Russia	− 656	− 633	3950	3910	3794	40	42	60
Leviy Aktru	Russia	− 190	− 320	3230	3250	3161	58	57	61
Maliy Aktru	Russia	− 140	− 300	3250	3270	3154	60	55	70
No. 125 (Vodopadniy)	Russia	− 260	− 270	3240	3240	3201	67	67	69
Maladeta	Spain	− 1787	− 947	> 3200	> 3200	3059	0	0	40
Mårmaglaciären	Sweden	− 1650	− 530	1655	1640	1599	11	13	34
Rabots Glaciär	Sweden	− 1630	—	1505	—	1372	19	—	51
Riukojietna	Sweden	− 1400	− 960	> 1450	> 1450	1332	0	0	55
Storglaciären	Sweden	− 1720	+ 410	1615	1480	1463	17	50	45
Tarfalaglaciären	Sweden	− 2530	+ 210	> 1790	1475	—	0	73	—
Basòdino	Switzerland	− 2501	− 902	> 3300	3100	2878	0	5	50
Findelen	Switzerland	− 1200	− 200	3350	3200	—	40	62	—
Gries [4]	Switzerland	− 1995	− 1473	3325	3324	2818	2	2	56
Silvretta [4]	Switzerland	− 1449	− 916	3071	2877	2760	2	21	55
Columbia (2057)	USA	− 980	− 370	1630	1575	—	40	60	69
Daniels	USA	− 1250	+ 120	—	—	—	34	62	69
Easton	USA	− 790	+ 260	2125	2075	—	50	70	—
Emmons	USA	− 940	− 430	2745	2539	—	40	51	—
Foss	USA	− 1020	− 380	—	—	—	36	54	65
Gulkana	USA	− 330	− 1250	1732	1809	1726	64	53	63
Ice Worm	USA	− 1350	− 620	—	—	—	20	48	70
Lemon Creek	USA	− 170	+ 150	1025	1000	1009	68	72	—
Lower Curtis	USA	− 1060	− 400	1710	1650	—	40	60	64
Lynch	USA	− 1050	+ 70	—	—	—	42	70	69
Nisqually	USA	− 760	− 1400	3000	3000	—	30	29	—
Noisy Creek	USA	− 320	− 360	1889	1825	1806	4	8	50
North Klawatti	USA	− 1140	− 740	2300	2165	2101	18	54	69
Rainbow	USA	− 610	+ 290	1730	1650	—	46	76	67
Sandalee	USA	− 400	− 60	2210	2160	—	40	60	—
Sholes	USA	− 710	− 210	—	—	—	44	72	—
Silver	USA	− 1010	− 650	2565	2560	2298	6	8	47
South Cascade [5]	USA	− 1620	− 210	> 2125	1880	1899	< 10	60	53
Taku	USA	+ 230	+ 480	975	930	976	82	84	—
Wolverine	USA	− 760	− 840	1188	1199	1148	62	61	64
Yawning	USA	− 930	− 130	—	—	—	54	70	—

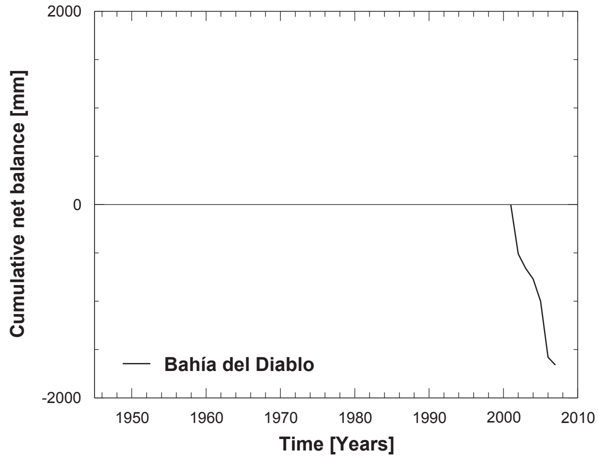
[1] Based on AAR values from 1961-1980.
[2] In 2005, Caresèr broke into two parts: Caresèr Orientale and Caresèr Occidentale.
[3] Perennial snowfield or glacieret
[4] The direct glaciological mass balance series was compared with the geodetic mass balance, and values of Silvretta from previous years have been adjusted (cf. Huss et al. 2009).
[5] Preliminary data, subject to revision.

2.2 CUMULATIVE SPECIFIC NET BALANCE GRAPHS

Notes:

- missing values are marked by gaps in the plotted data series with graphs restarting with the value of the previous available data point
- y-axis are scaled according to the data range of the cumulative net balance graph

ANTARCTICA



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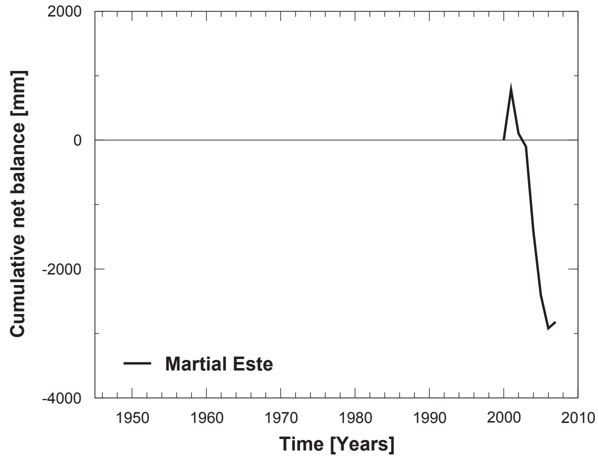

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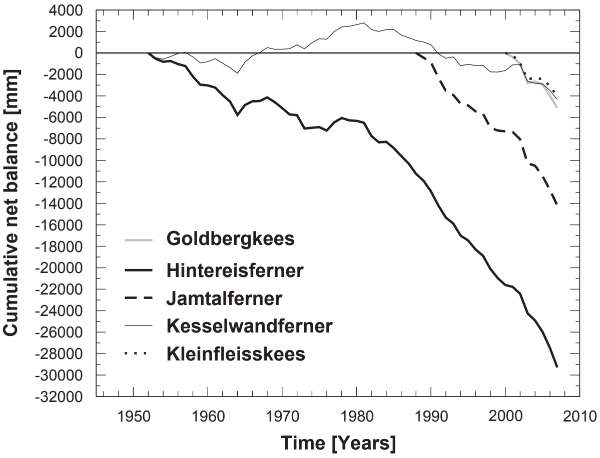

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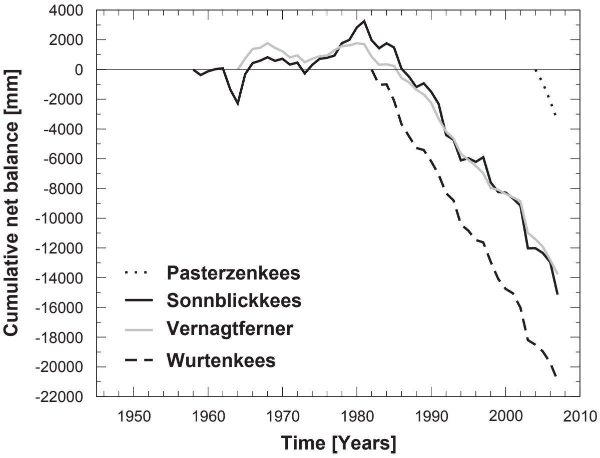

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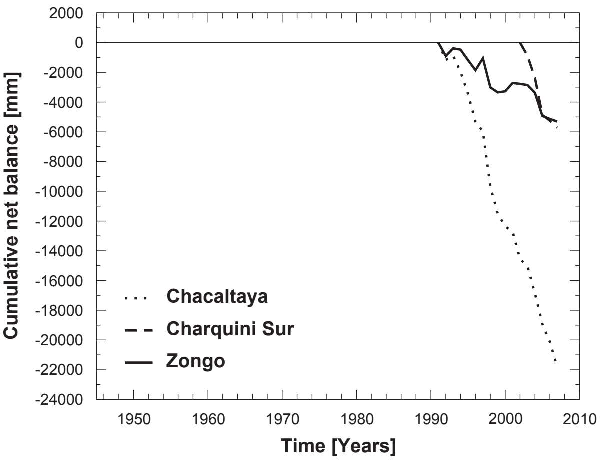

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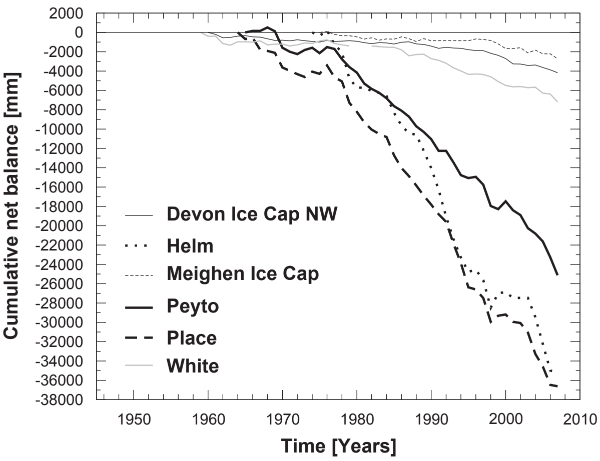

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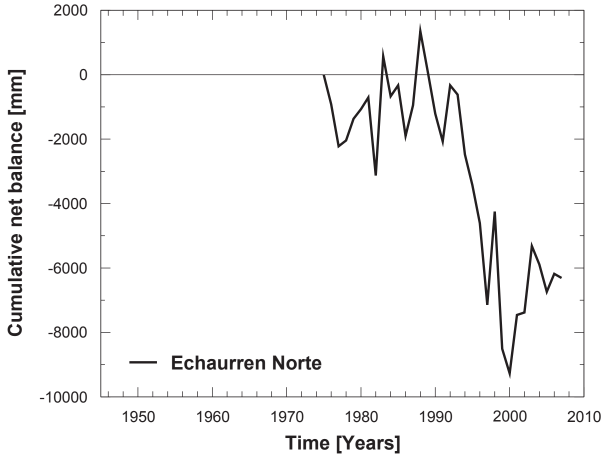

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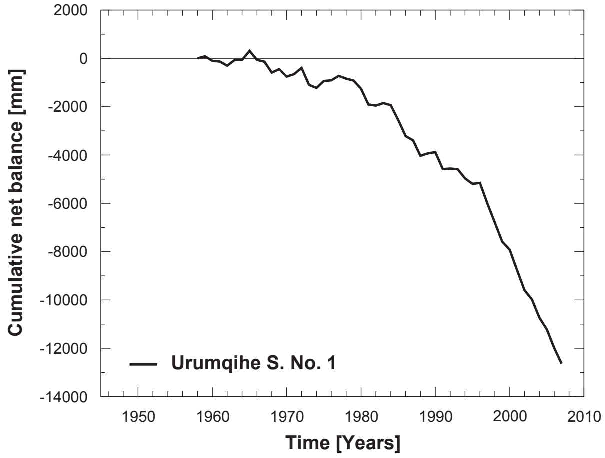

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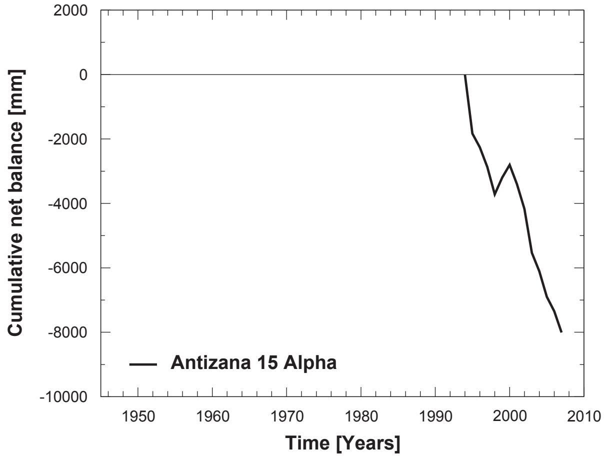

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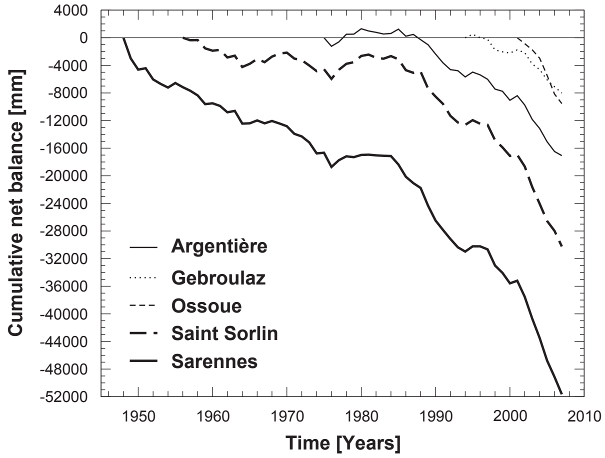

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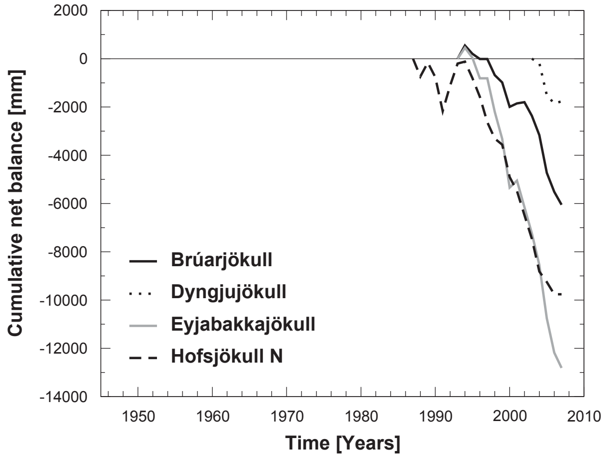

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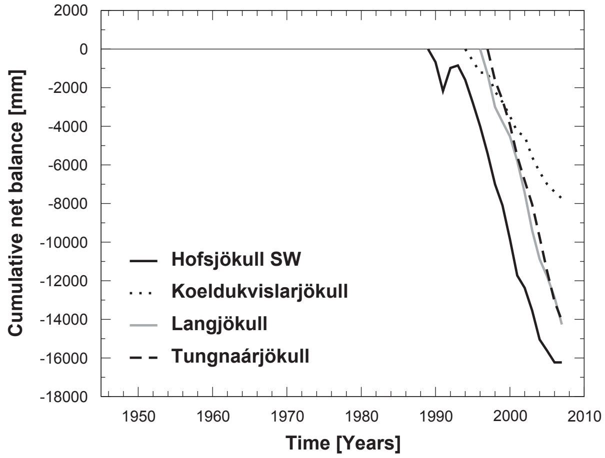

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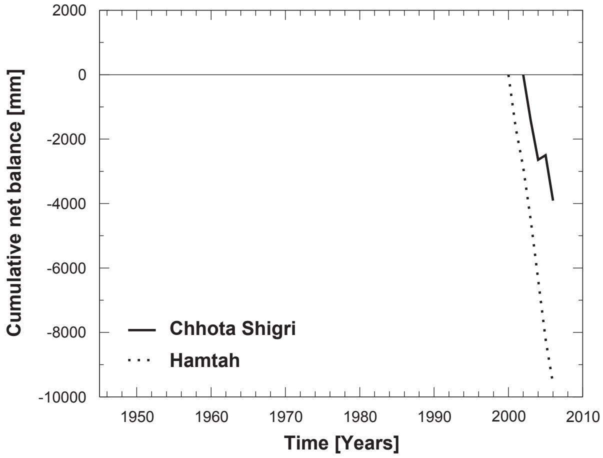

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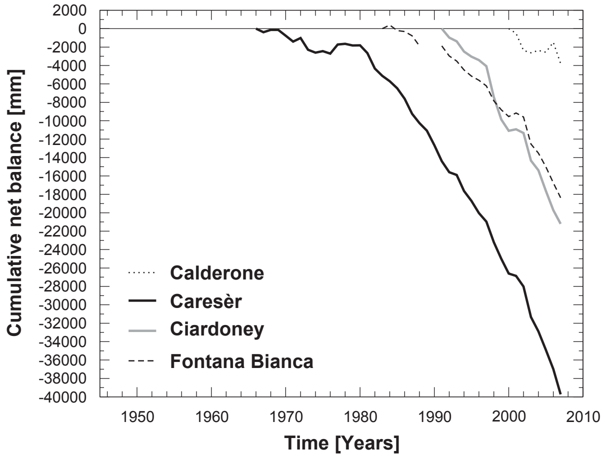

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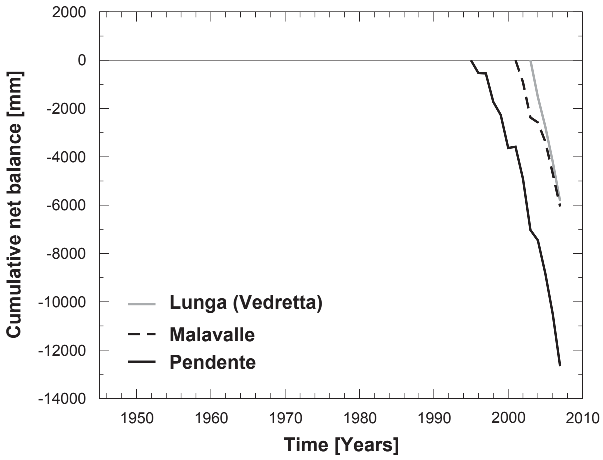

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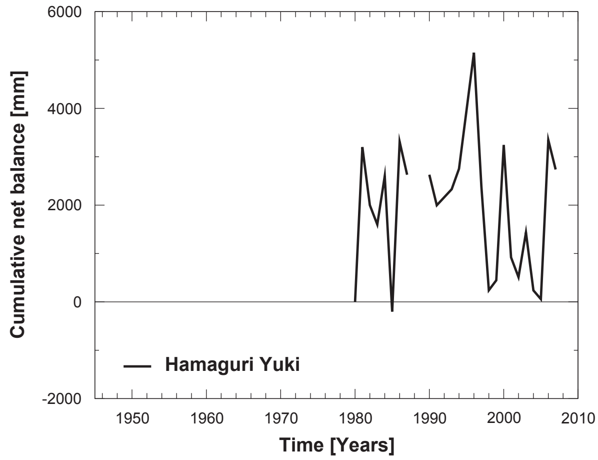

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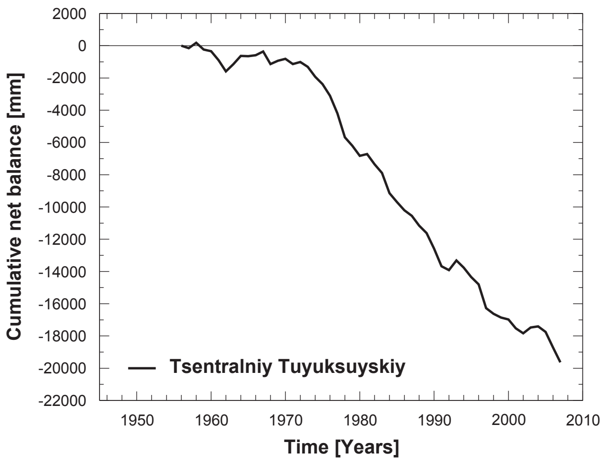

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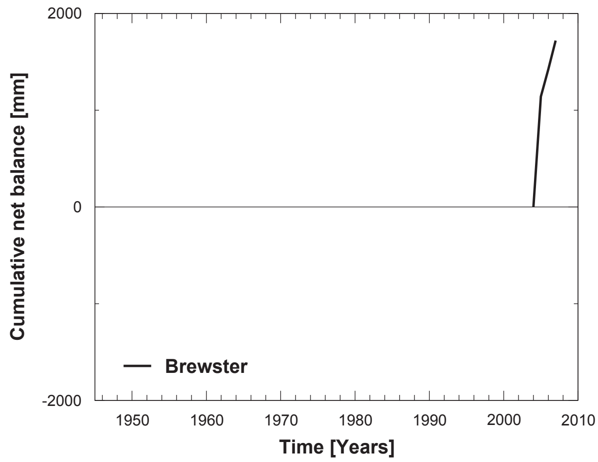

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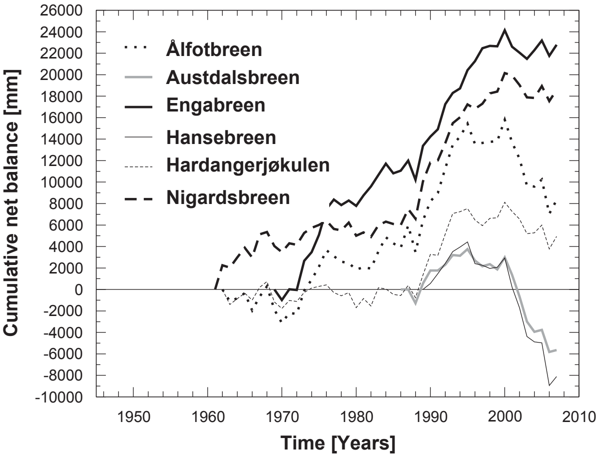

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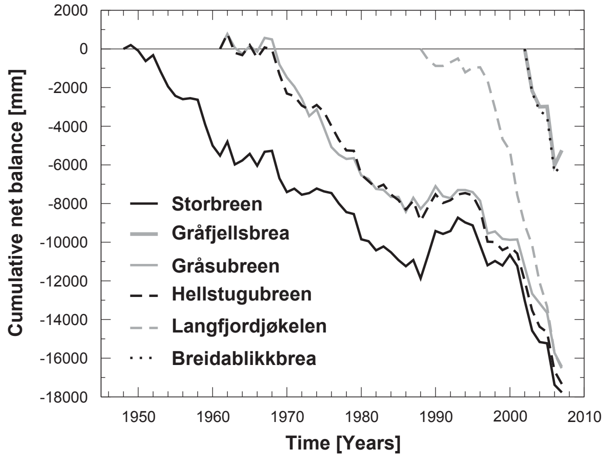

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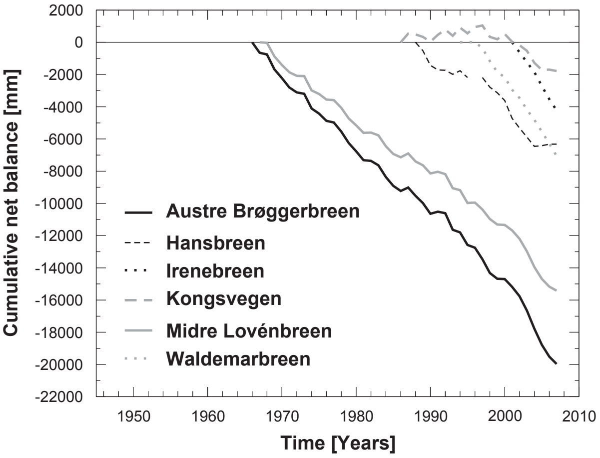

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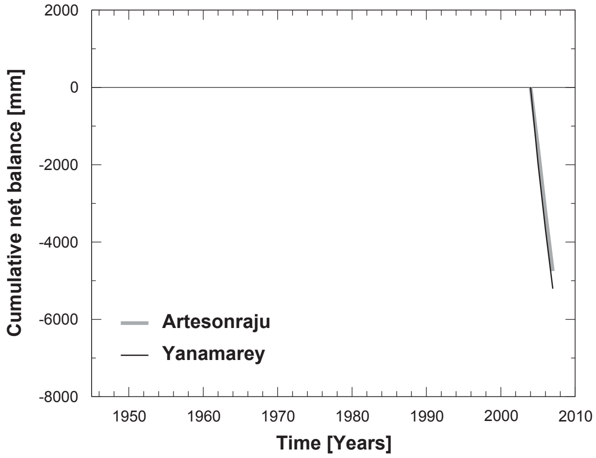
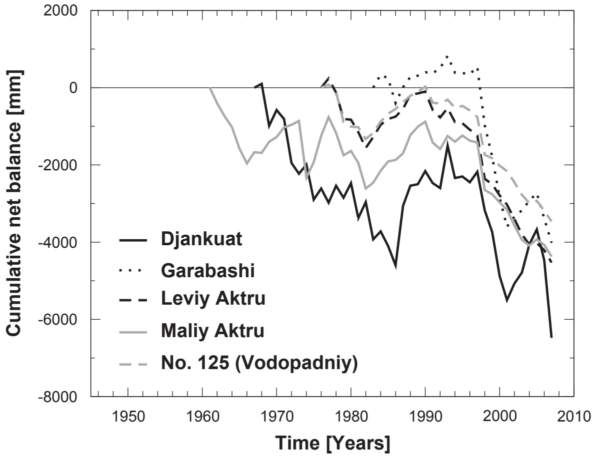


RUSSIA



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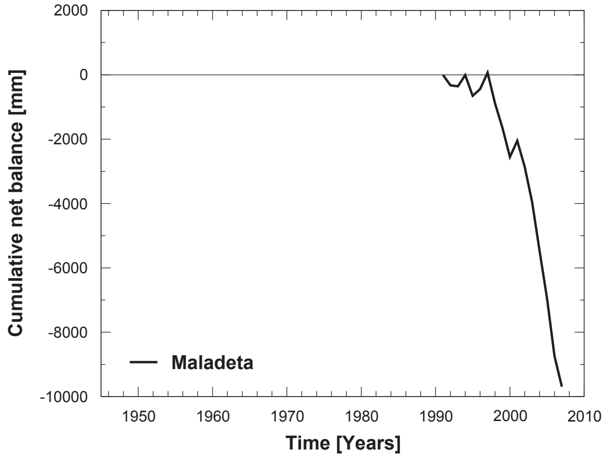

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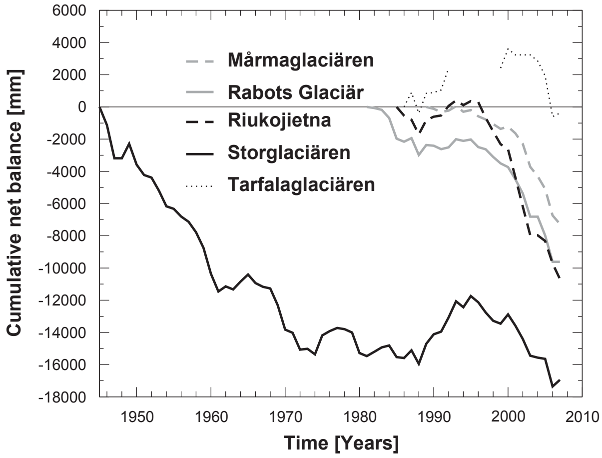

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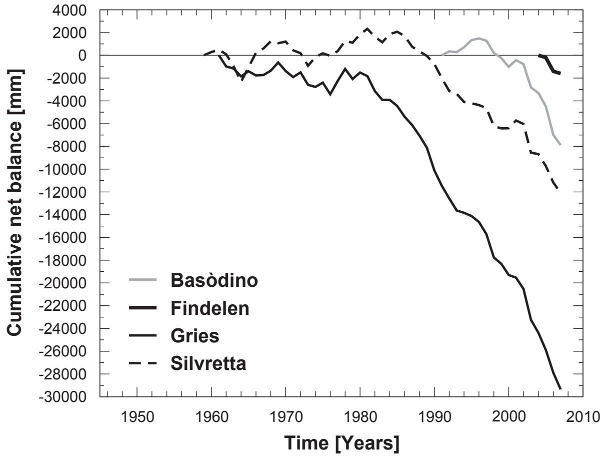

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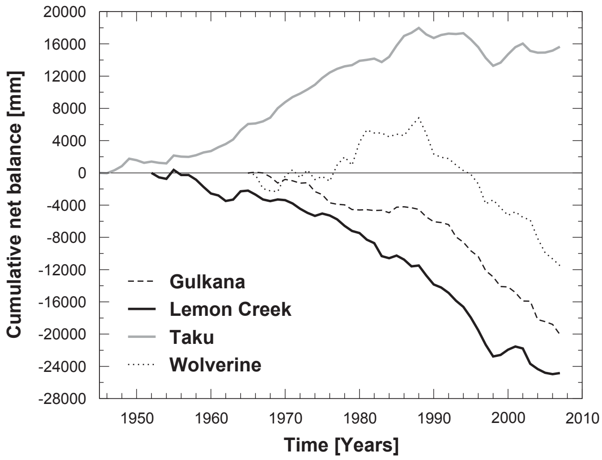

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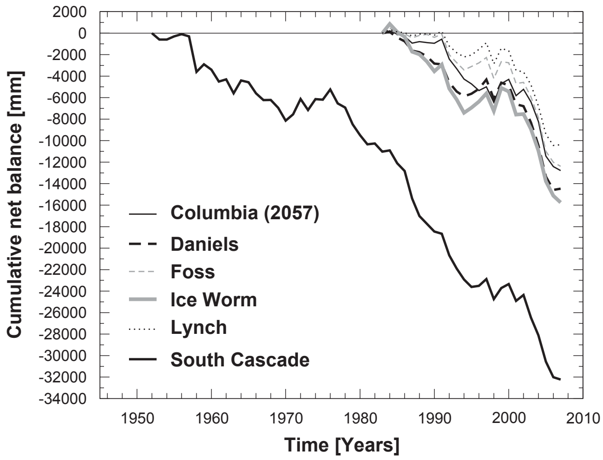
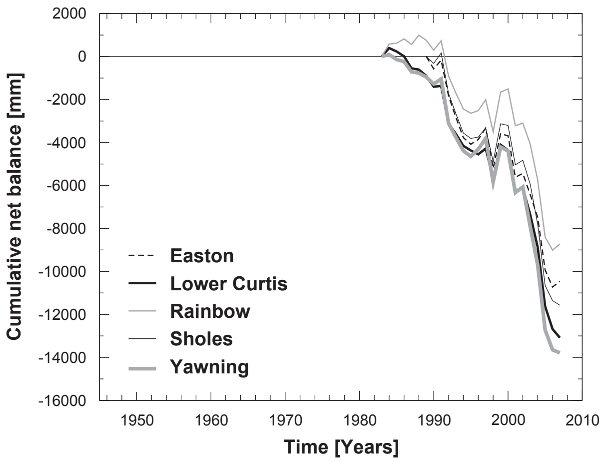
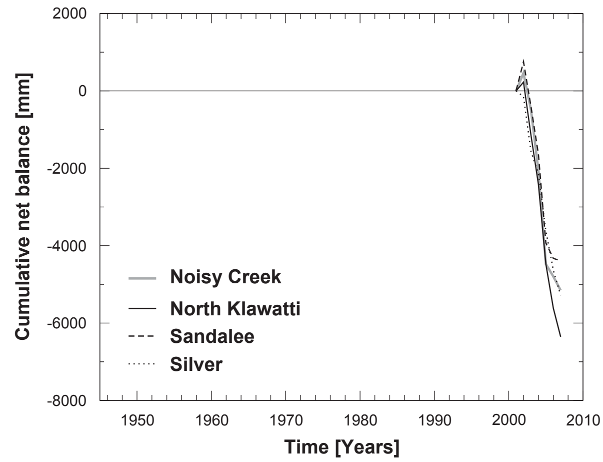


USA (WASHINGTON 2)



USA (WASHINGTON 3)



3 DETAILED INFORMATION

More detailed information about selected glaciers in various mountain ranges – with ongoing direct glaciological mass balance measurements – is presented here, in addition to the basic information contained in the previous chapter. In order to facilitate comparison between the individual glaciers, the submitted material (text, maps, graphs and tables) was standardized and rearranged.

The text gives general information on the glacier followed by brief comments on the two reported balance years. General information concerns basic geographic, geometric, climatic and glaciological characteristics of the observed glacier which may help with the interpretation of climate/glacier relationships. An oblique photograph showing the glacier is included.

Three maps are presented for each glacier: the first one, a topographic map, shows the stake, snow pit and snow probing network. This network is basically the same from one year to the next on most glaciers. In cases of differences between the two reported years, the second was chosen, i.e., the network from the year 2006/07. The second and third maps are balance maps from the reported years, illustrating the pattern of ablation and accumulation. The accuracy of such balance maps depends on the density of the observation network, the complexity of the mass balance distribution and the experience of the local investigators.

A graph of net mass balance versus altitude is given for both reported years, overlain with the corresponding glacier hypsography. The relationship between mass balance and altitude – the mass balance gradient – is an important parameter in climate/glacier relationships and represents the climatic sensitivity of a glacier. It constitutes the main forcing function of glacier flow over long time intervals. Therefore, the mass balance gradient near the equilibrium line is often called the 'activity index' of a glacier. The glacier hypsography reveals the glacier elevation bands that are most influential for the specific net balance, and indicates how the specific net balance changes with a shift of the ELA. Some of the elevation bands are irregular, especially the lowest and highests values. The elevation bands represent the submitted altitude intervals.

The last two graphs show the relationship between the specific net balance and the accumulation area ratio (AAR) and the equilibrium line altitude (ELA) for the whole observation period. The regression equation is given at the top of both diagrams. The AAR regression equation is calculated using integer values only (in percent). AAR values of 0 or 100 % as well as corresponding ELA values outside the altitude range of the observed glaciers were excluded from the regression analysis. Such regressions were used to determine the AAR_0 and ELA_0 values (cf. Chapter 2). The points from the two reported balance years (2005/06 and 2006/07) are marked in black. Minimum sample size for regression was defined as 6 ELA or AAR values.

3.1 BAHÍA DEL DIABLO (ANTARCTICA/A. PENINSULA)

COORDINATES: 63.82 S / 57.43 W

Photo taken by P. Skvarca on 1st of March 2005.

This polythermal outlet-type glacier is located on Vega Island, north-eastern side of the Antarctic Peninsula. The glacier is exposed to the north-east, covers an area of 14.3 km^2 and extends from an altitude of 630 m to 75 m a.s.l. The mean annual air temperature at the equilibrium line around 400 m a.s.l. ranges between −7 and −8 °C. The snout of the glacier overrides an ice-cored moraine over a periglacial plain of continuous permafrost.

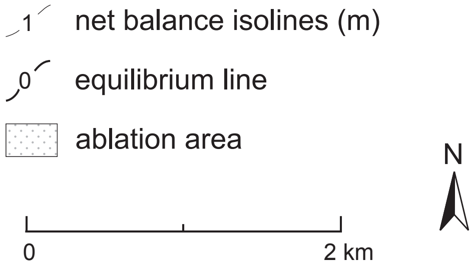
Detailed mass balance measurements of this glacier began in austral summer 1999/00. A simplified version of combined stratigraphic-annual mass-balance method is applied because the glacier can be visited only once a year. Despite the relatively low mean annual temperature of −5.8 °C, the balance year 2005/06 resulted in −580 mm w.e., the most negative mass budget recorded since the initiation of measurements. This lowest value is probably due to a very high mean summer air temperature of +1.6 °C combined with strong north-westerly warm katabatic winds, which enhanced melting. By contrast, the net budget of only −80 mm w.e. for balance year 2006/07 figures among the lowest in the record because of low mean summer temperature of +0.2 °C, yielding only 96 melt-days. The additional two years of detailed mass balance data further confirm a strong correlation existing in this region between the annual net balance and the mean summer air temperature.

3.1.1 Topography and observation network

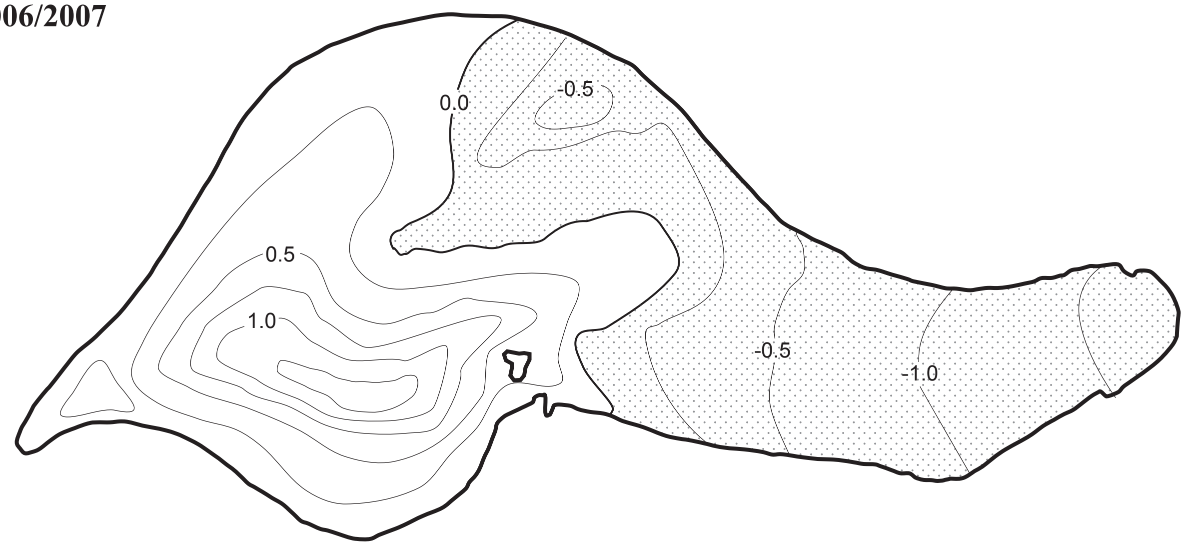
Glaciar Bahía del Diablo (ANTARCTICA)

3.1.2 Net balance maps 2005/2006 and 2006/2007

2005/2006

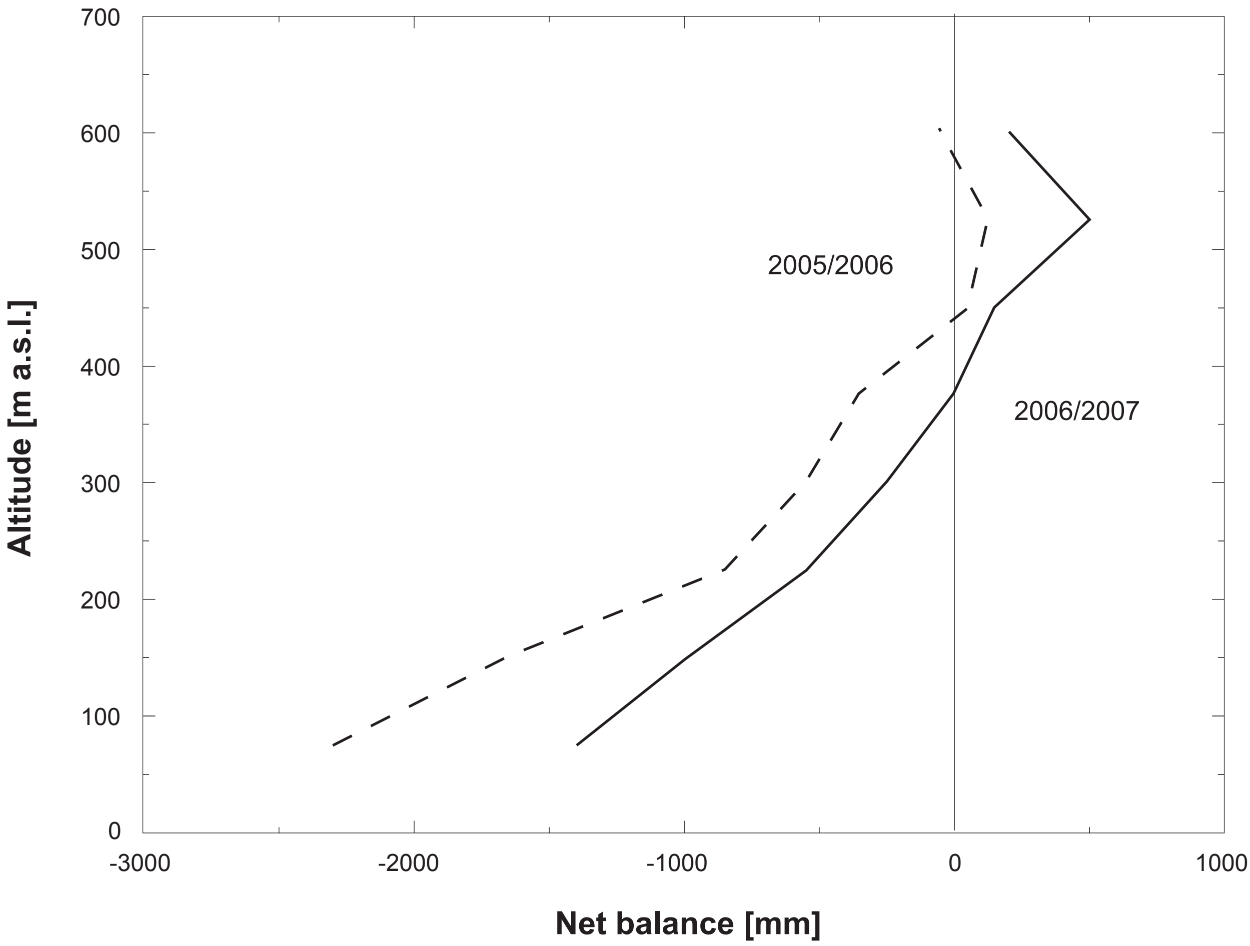


2006/2007

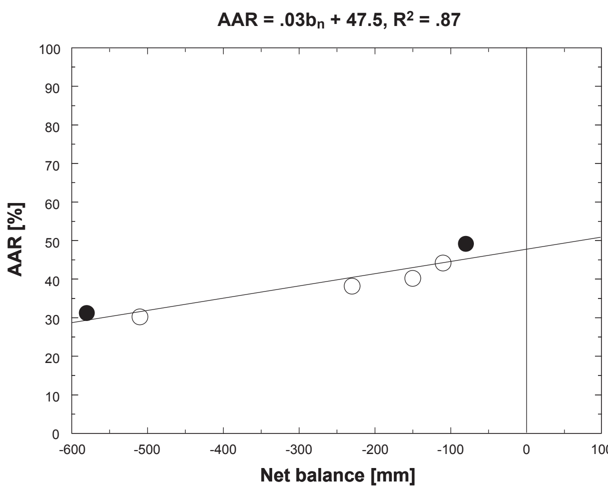


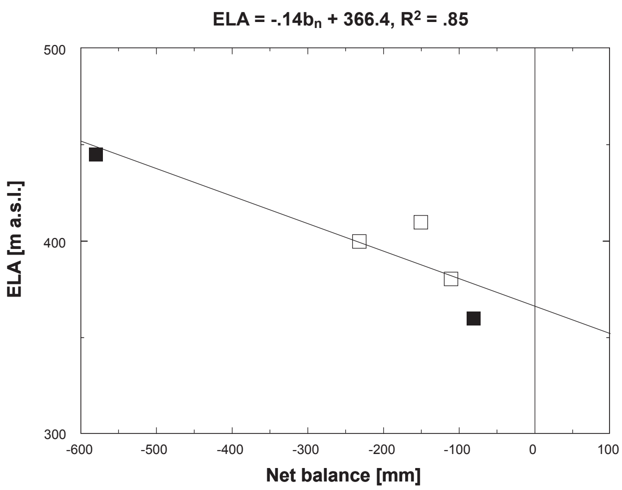
Glaciar Bahía del Diablo (ANTARCTICA)

3.1.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.1.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





Glaciar Bahía del Diablo (ANTARCTICA)

3.2 MARTIAL ESTE (ARGENTINA/ANDES FUEGUINOS)

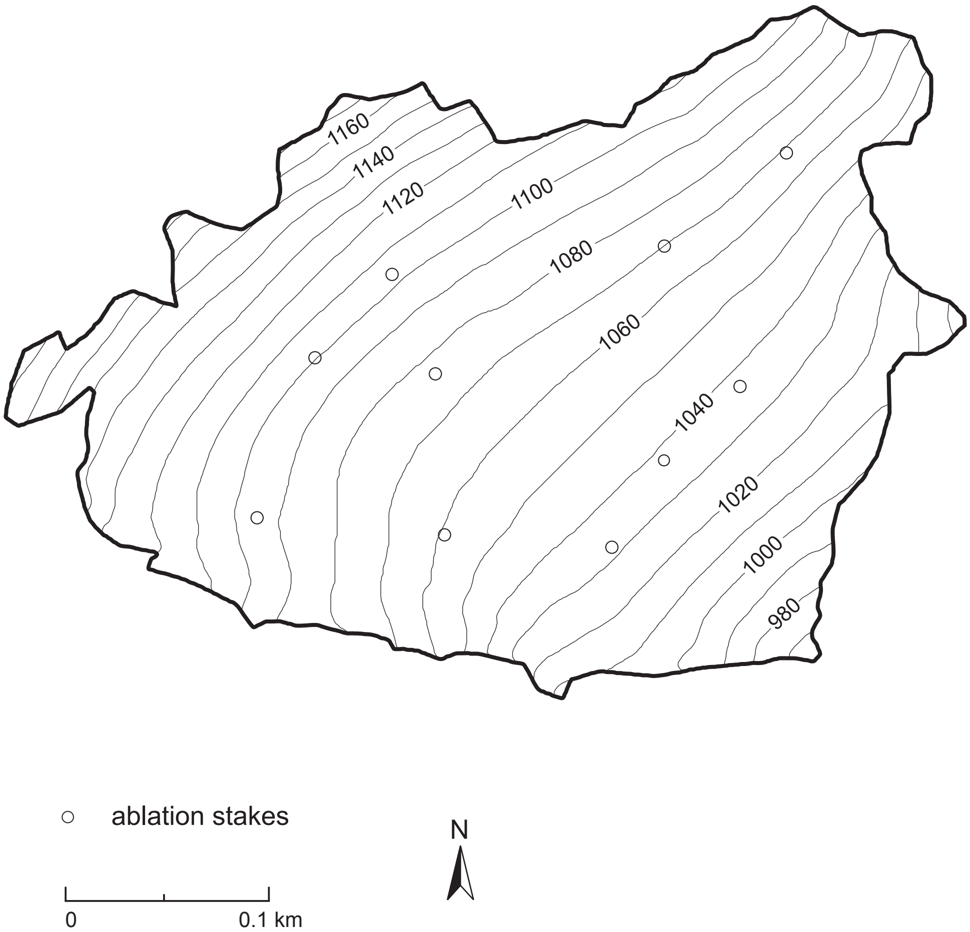
COORDINATES: 54.78 S / 68.40 W

Photo taken by R. Iturraspe in February 2006.

The Martial Este is one of the four small glaciers that remain in the well-defined glacial cirque of the Cordon Martial (1319 m a.s.l at Mt Martial) very close to Ushuaia city and to the Beagle channel. Glacier runoff contributes to the water supply of this city. Total ice area on this cirque reaches 0.33 km^2. The Martial Este glacier (the body at the right of the photo) has a surface area of 0.1 km^2 that extends from 1180 m to 970 m a.s.l. with a medium slope of 29° and south-east exposition. It receives less direct solar radiation than the rest of the glaciers on the cirque. Mean annual air temperature at the equilibrium line is −1.5 °C and the average precipitation amounts to 1300 mm, distributed over the whole year. The rain regime has no dry season. The hydrological cycle starts in April and the maximum accumulation on the glacier is reached in October or November. Since the Little Ice Age these glaciers have lost 75 % of their total area. From 1984 to 1998 vertical thinning at the Martial Este Glacier was 7.0 m (450 mm w.e. a^{-1}) based on topographic surveys.

During the hydrological years 2005/06 and 2006/07, the net balance of the Martial Este glacier was more stable than observed in the previous biannual period. In the first year, the deficit was −510 mm w.e., which is close to the computed average from 1984. Precipitation in 2006/07 was the highest in the last 25 years; however that represents just 21 % of the historical average. Snowfalls and cold conditions during the late spring also favored a positive balance, but dry and warm conditions in January and February caused rapid melting. However, the balance was weakly positive (+ 99 mm w.e.) for the first time since 2000/01.

3.2.1 Topography and observation network

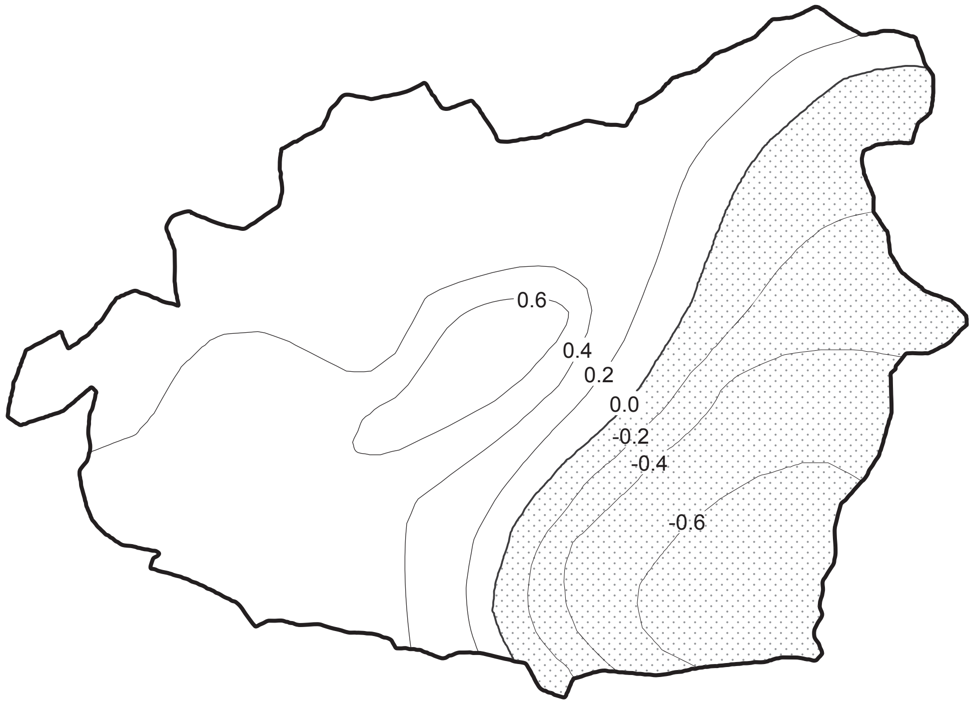


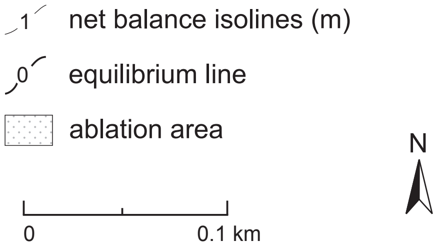
Martial Este (ARGENTINA)

3.2.2 Net balance maps 2005/2006 and 2006/2007

2005/2006

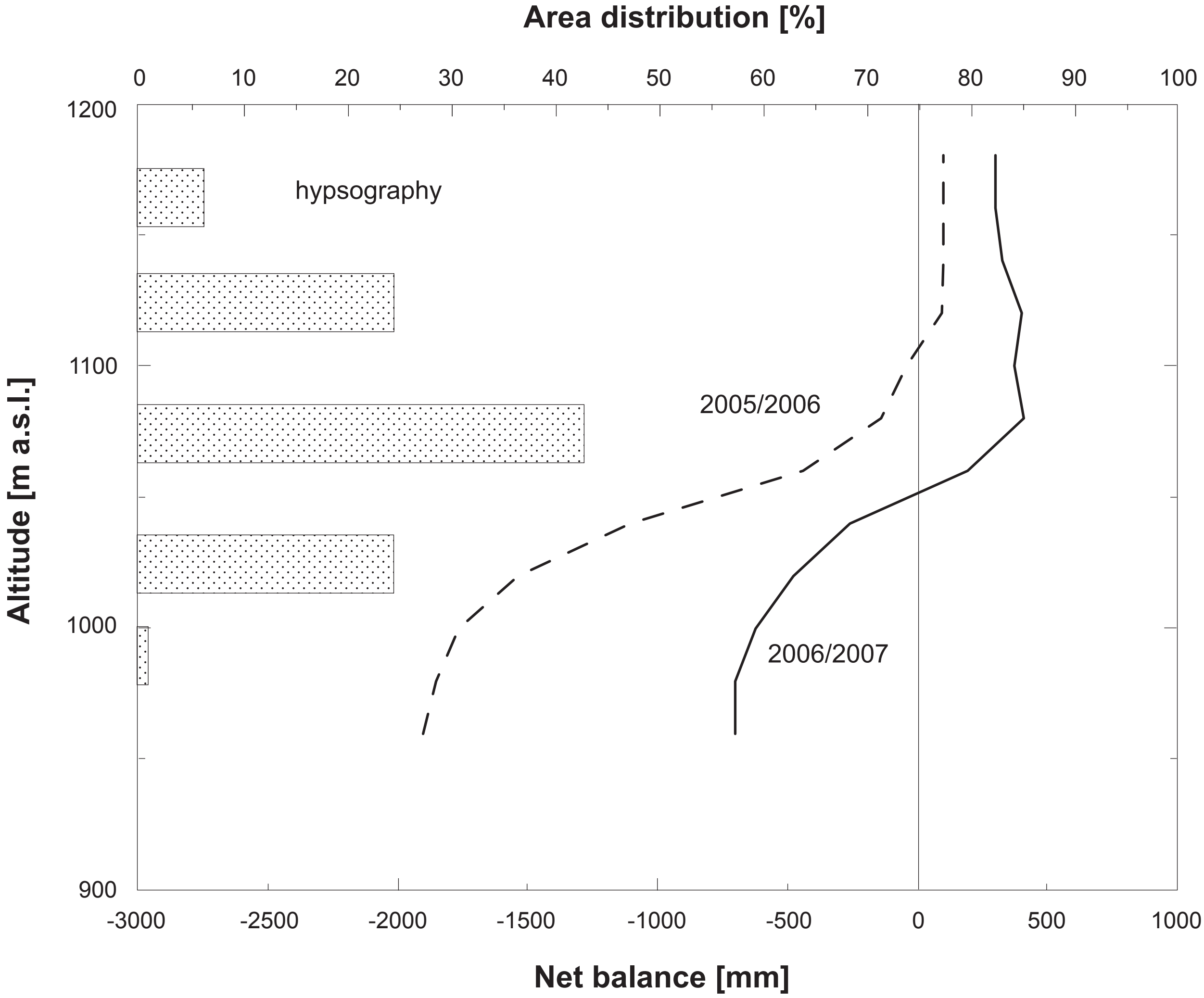
2006/2007



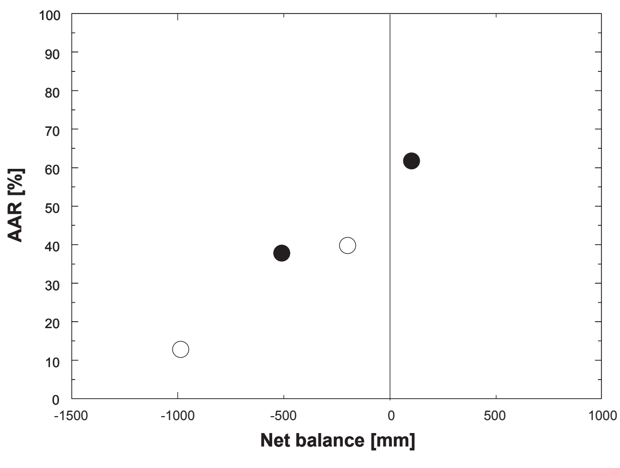


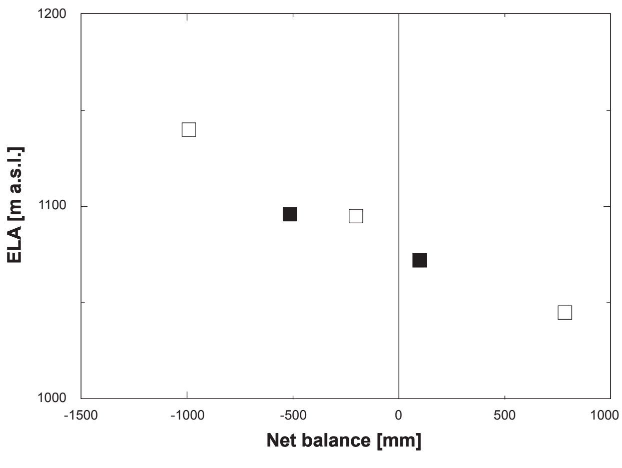
Martial Este (ARGENTINA)

3.2.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.2.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





Martial Este (ARGENTINA)

3.3 HINTEREISFERNER (AUSTRIA/EASTERN ALPS)

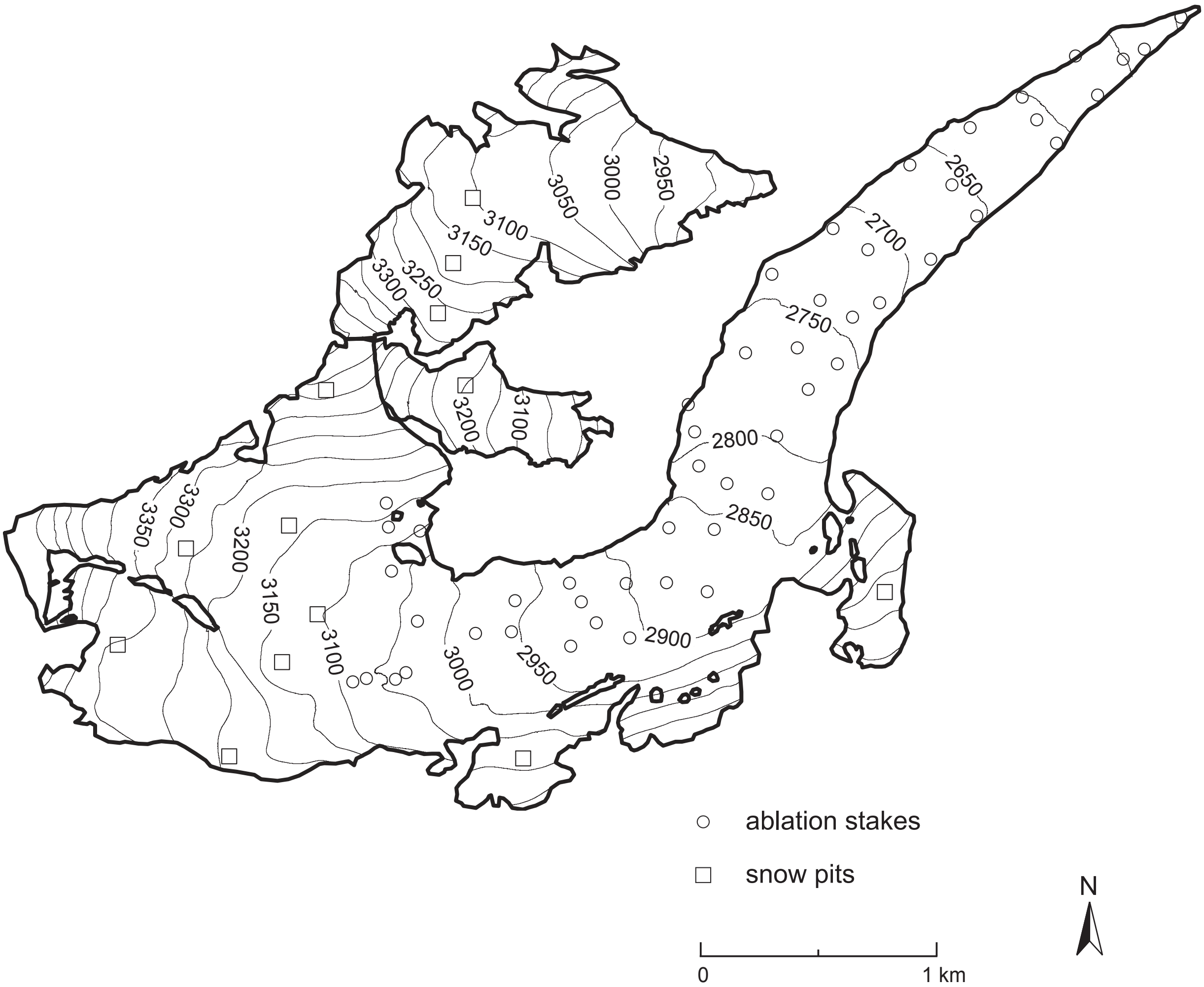
COORDINATES: 46.80 N / 10.77 W

Photo taken by A. Lambrecht on 12th of September 2006.

The mass balance of Hintereisferner has been measured with the direct glaciological method since 1952/53. Hintereisferner is a valley glacier which had several tributary glaciers in 1953. In the meantime, most of these tributary glaciers have lost connection to the main tongue. The last to separate so far was Langtaufererjochferner in 2000. The glacier area decreased from 10.24 km^2 in 1953 to 7.40 km^2 in 2006 and 7.21 km^2 in 2007. The highest point of Hintereisferner is the Weißkugel/ Pala Bianca peak with an altitude of 3739 m a.s.l. The tongue is located in a north-east orientated valley, the firn area faces north, east and south. The lowest point was 2350 m a.s.l. in 1953 and 2750 m a.s.l. in 2007. The ice thickness losses between 1953 and 2007 exceeded 160 m on parts of the glacier tongue, but were only a few meters in parts of the firn area. In the mass balance year 2002/03 the topographic basis was changed from the DEM of the glacier inventory dating from 1997 to the airborne laser scan DEM of October 2001. In addition to the annual geodetic surveys, several airborne Laser Scan DEMs were compiled between 2001 and 2008. The mean annual air temperature at the ELA_0 is about -4 °C, as estimated from the temperature measurements at the Vent climate station (1906–2005; 1906 m a.s.l.). A mean annual precipitation of 1374 mm was measured at a nearby totalizer (1963–2008; 2970 m a.s.l.).

In 2005/06 the mean air temperature was exactly the long term mean, in 2006/07 it was 3.7 °C. The mean annual lapse rate is assumed to be 0.0057 °C m^{-1}. The specific mass balance was −1516 mm w.e. in 2005/06 and −1798 mm w.e. in 2006/07. The ELA was above the summits in both hydrological years.

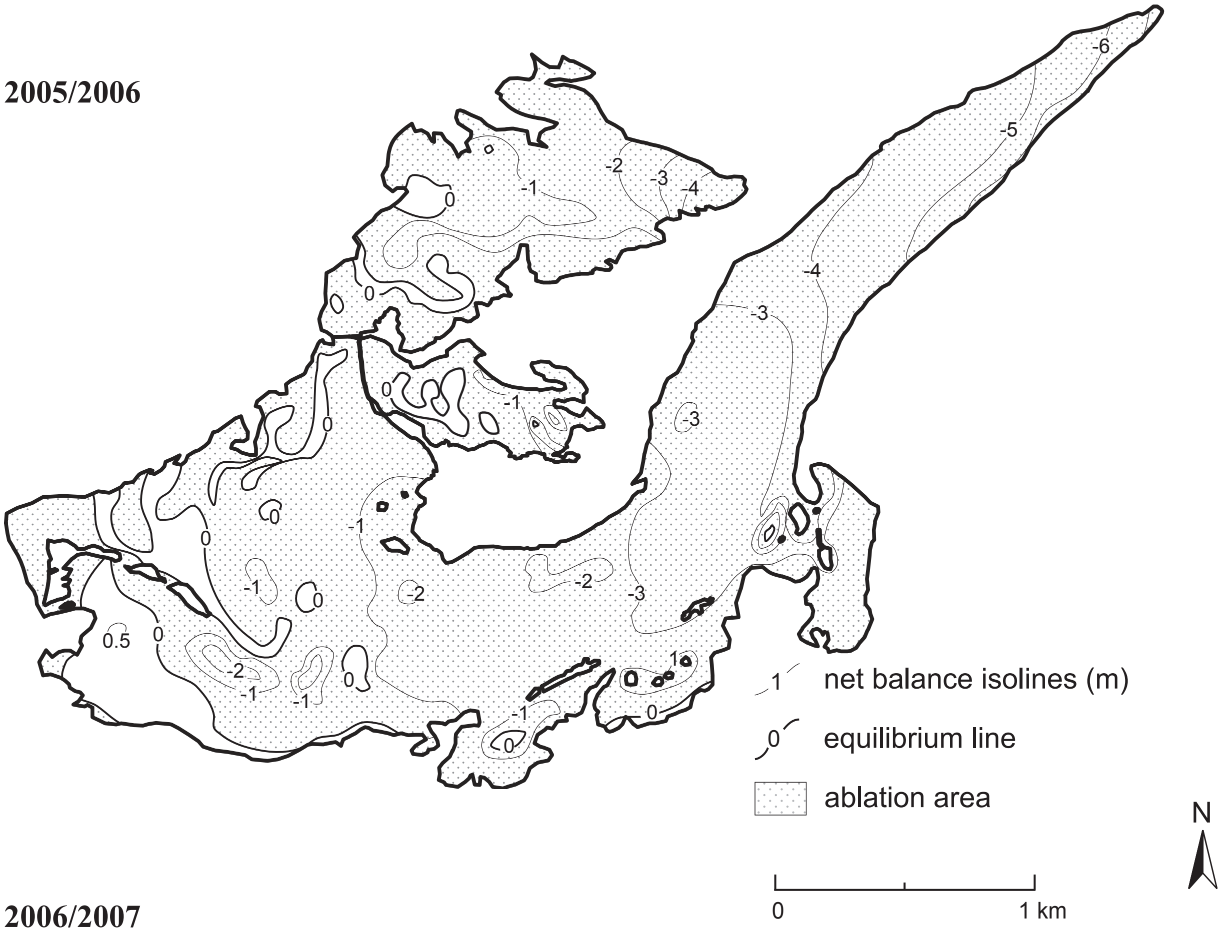
3.3.1 Topography and observation network



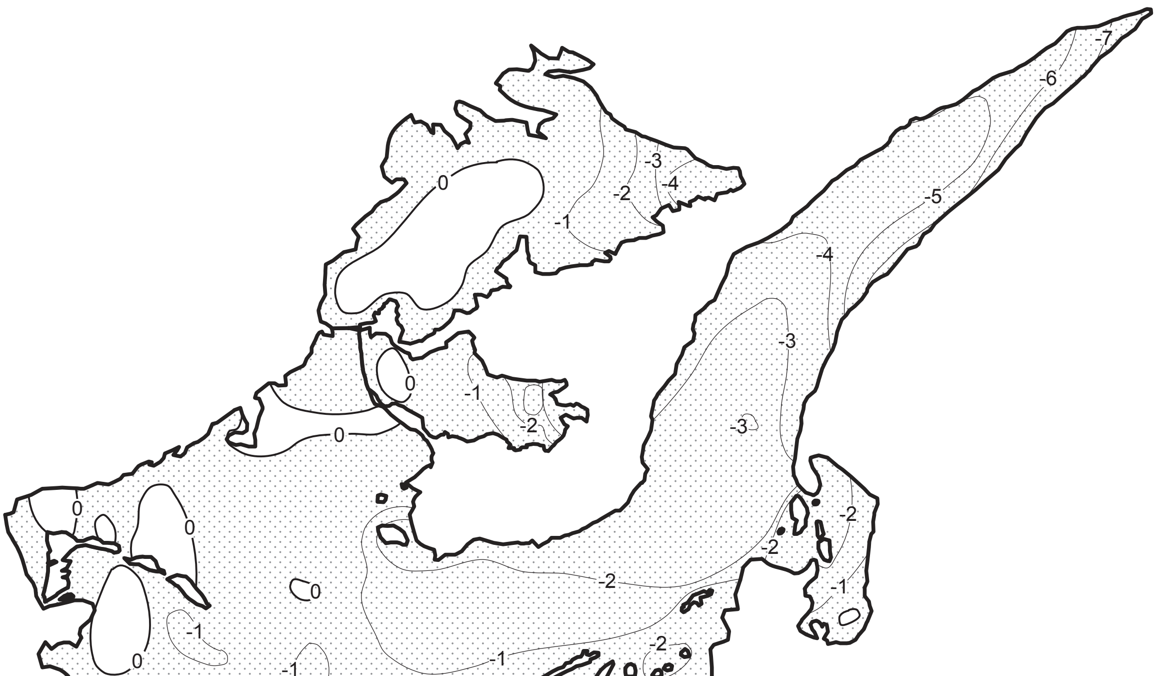
Hintereisferner (AUSTRIA)

3.3.2 Net balance maps 2005/2006 and 2006/2007

2005/2006

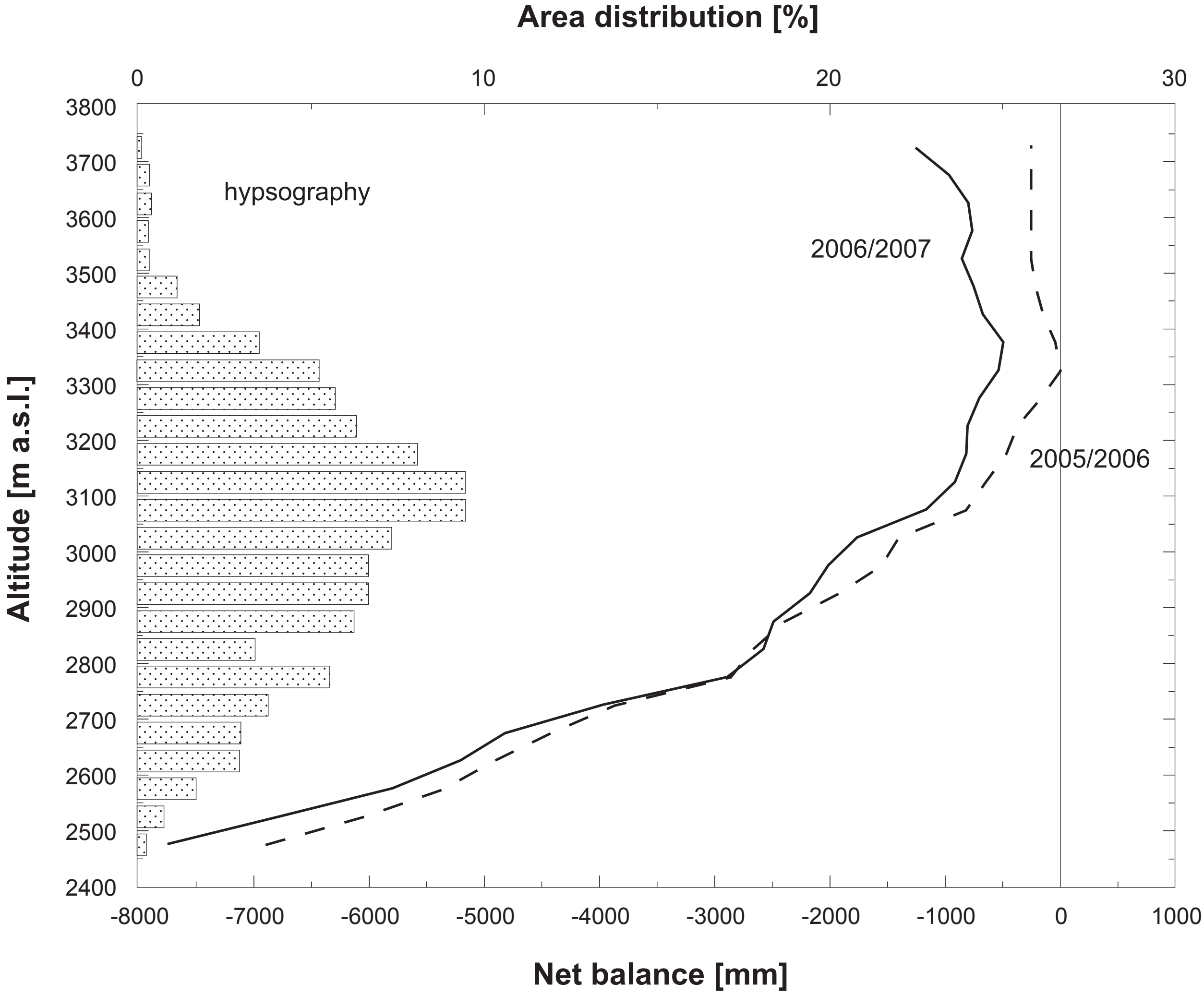


2006/2007

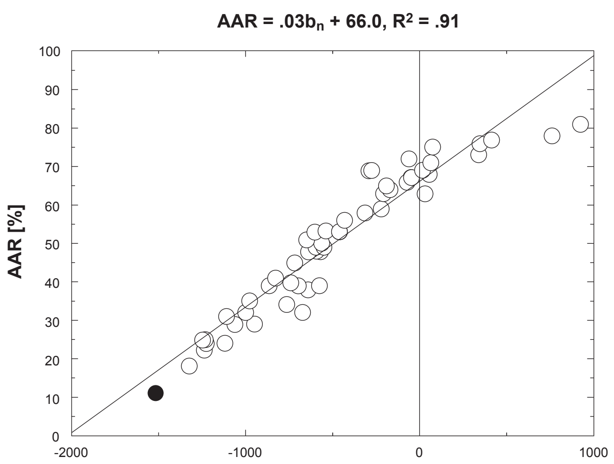


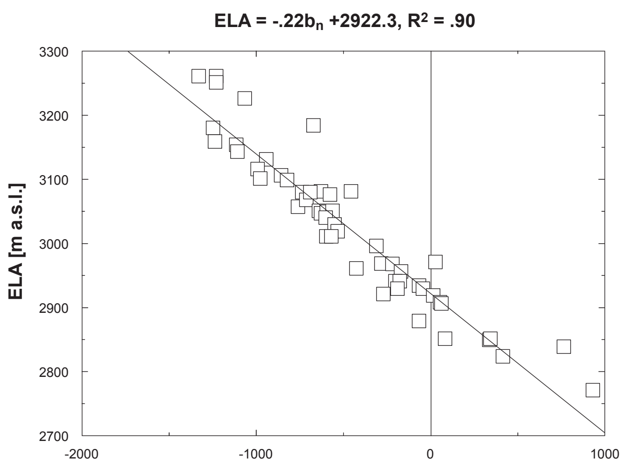
Hintereisferner (AUSTRIA)

3.3.3 Net balance versus altitude 2005/2006 and 2006/2007



3.3.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





Hintereisferner (AUSTRIA)

3.4 ZONGO (BOLIVIA/TROPICAL ANDES)

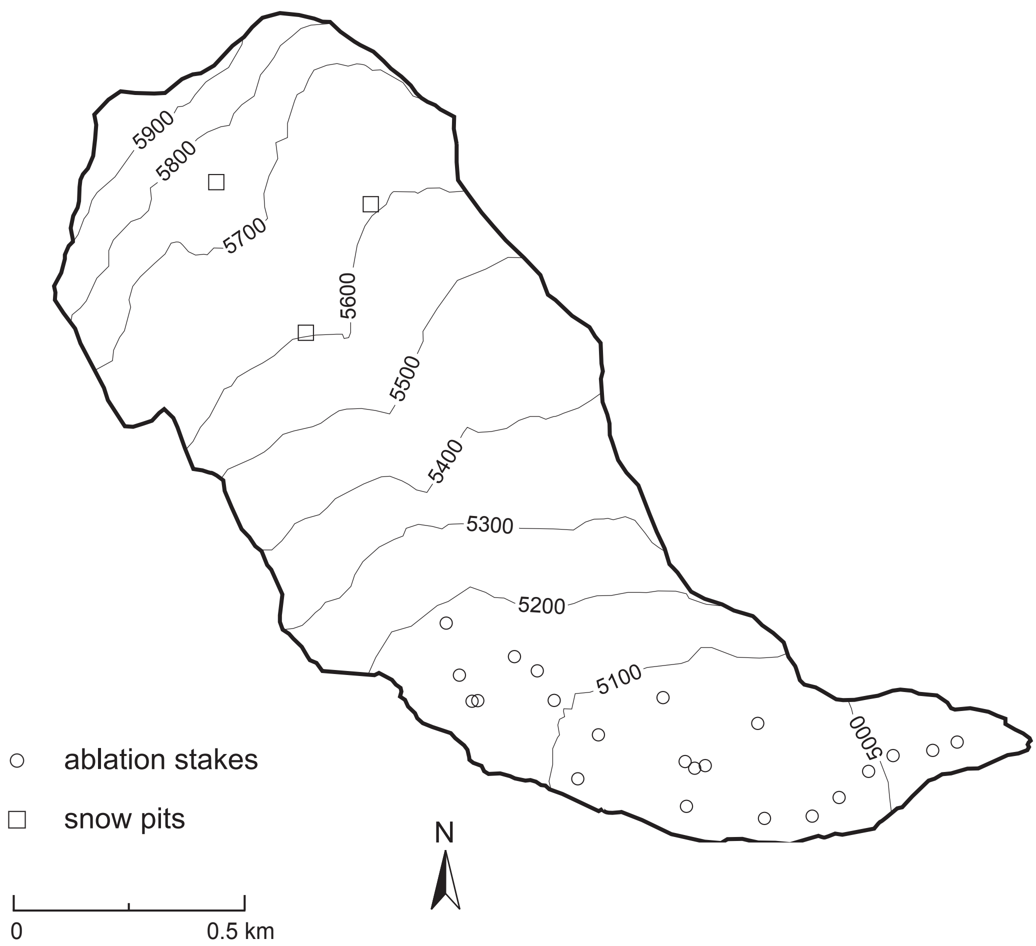
COORDINATES: 16.25 S / 68.17 W

Photo provided by P. Ginot in 2007.

Zongo is a small valley glacier located north-east of La Paz, at the headwaters of a large system of power plants supplying the city. It is a glacier 2.2 km long, between 6000 m and 4900 m a.s.l., with an surface area of 1.9 km^2. Exposure is to the south in the upper part and to the east at the lower tongue. The average annual air temperature is −1.5 °C at the ELA (5250 m a.s.l.) and an average annual rainfall of 900 mm (± 150 mm) measured at 4770 m a.s.l. The region has a climate characterized by a dry season and a wet season. The latter occurs in the summer when the ablation reaches its maximum from November to February, with the highest precipitation period from January to March. Like all glaciers in the region, it has generally presented yearly negative mass balances, with few exceptions, with the greatest loss occurring during the 1997–1998 El Niño event (approximately −2000 mm w.e.). The few periods of light positive mass balances have coincided with La Niña events.

The 2005/06 period presents a slightly negative mass balance (−197 mm w.e.). The ENSO index of the observation period was characterized by a weak positive anomaly in the Pacific (Niño phenomenon) at the beginning and negative anomaly (Niña phenomenon) towards the end of the hydrological year. The period 2006/07 presented an almost balanced mass balance (−173 mm w.e.), due to a slightly more humid period with precipitation 7 % above normal.

3.4.1 Topography and observation network

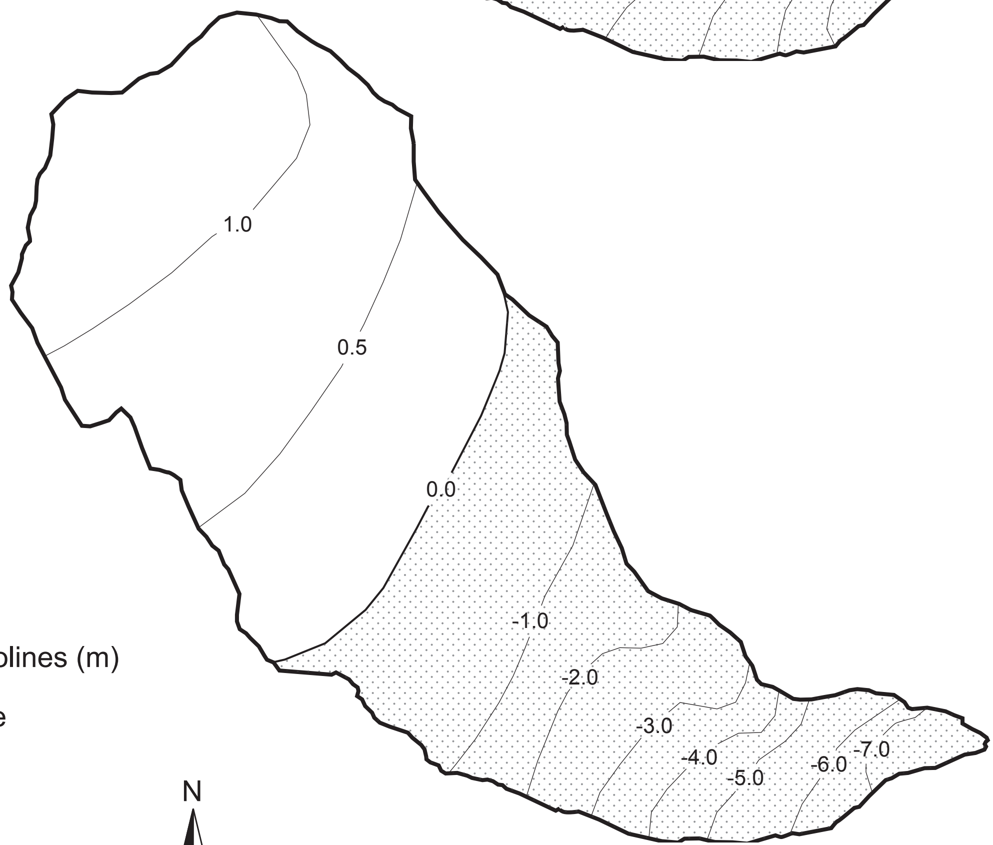


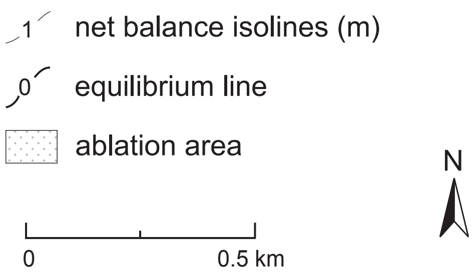
Zongo (BOLIVIA)

3.4.2 Net balance maps 2005/2006 and 2006/2007

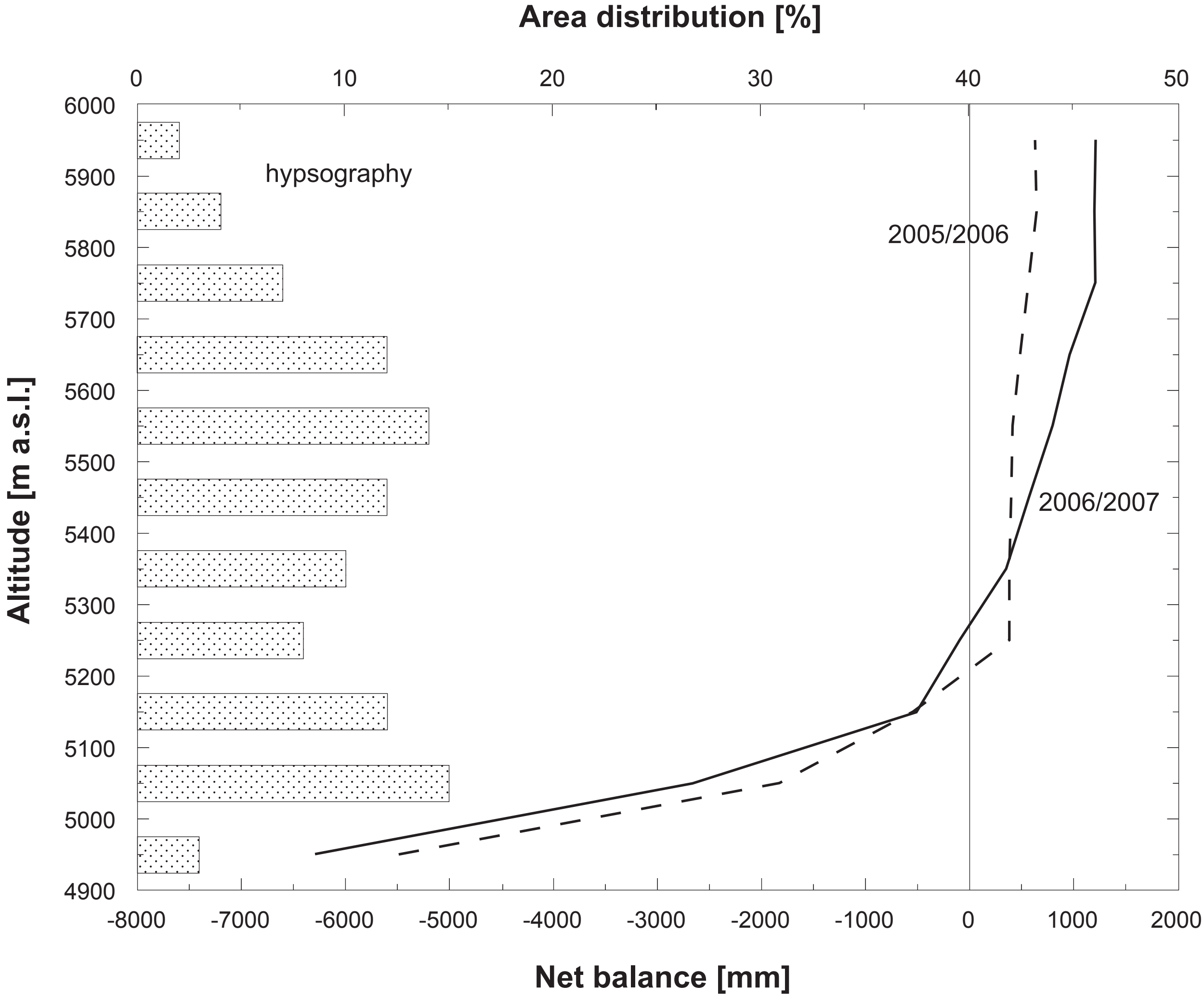
2005/2006

2006/2007

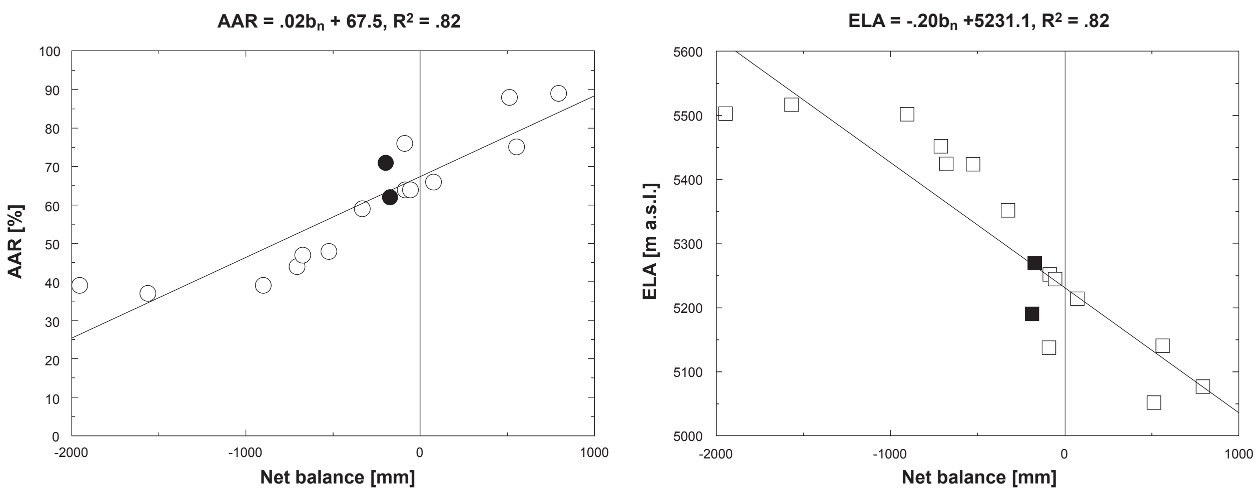




3.4.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.4.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period



Zongo (BOLIVIA)

3.5 WHITE (CANADA/HIGH ARCTIC)

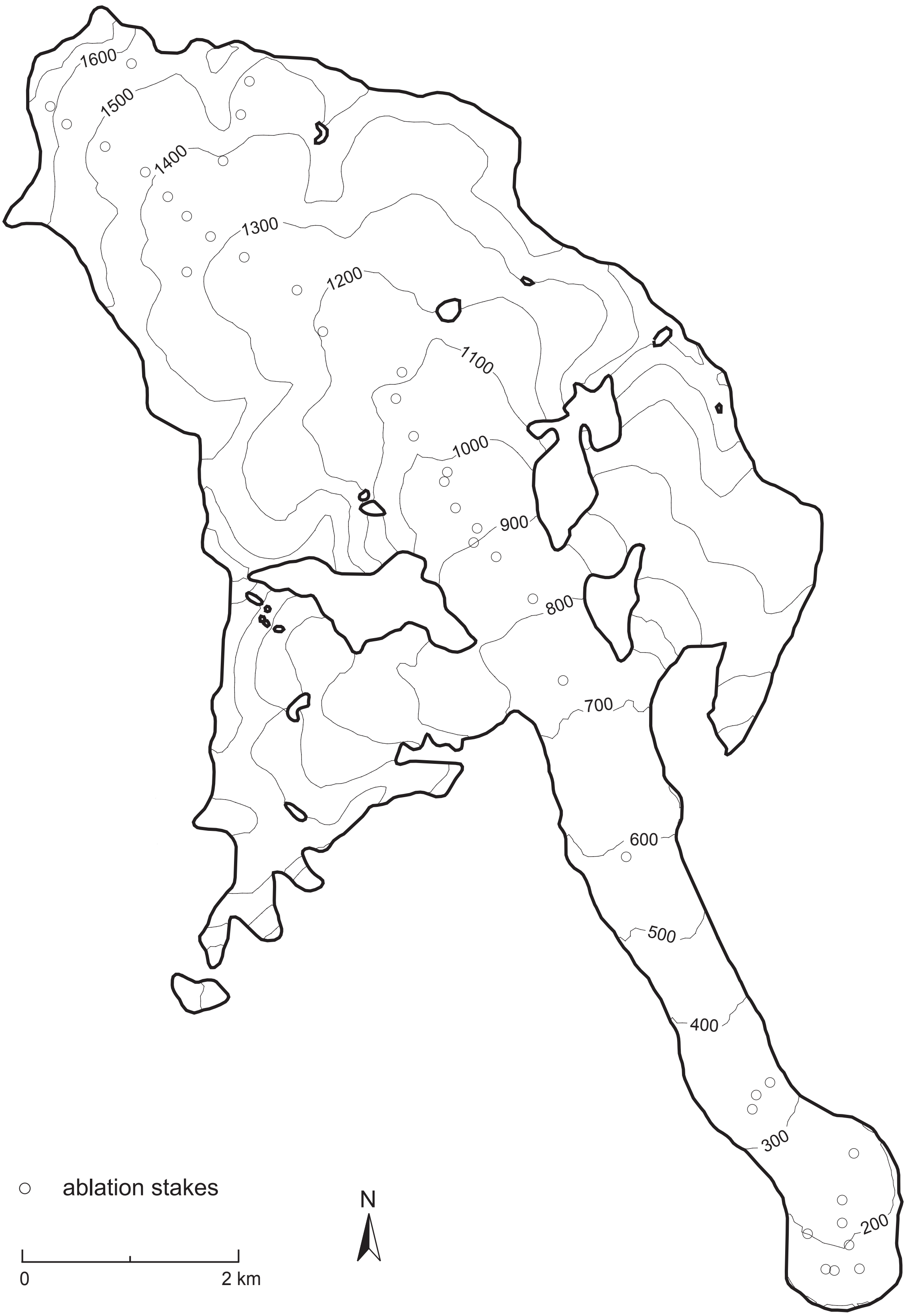
COORDINATES: 79.45 N / 90.67 W

Aerial view of White Glacier taken on 2 July, 2008. Photo by J. Alean.

White Glacier is a valley glacier in the Expedition Fiord area of Axel Heiberg Island, Nunavut. It extends in elevation from 1782 m to 85 m a.s.l. and at present occupies 39.4 km^2, having shrunk by gradual retreat of its terminus from an extent of 40.2 km^2 in 1960. Sea level temperature in the Expedition Fiord area averages about −20 °C, but the glacier is known to have a bed which is partly unfrozen, at least beneath the valley tongue; ice thickness is typically 200 m, but reaches or exceeds 400 m. Annual precipitation at sea level is very low, about 100 mm, although annual accumulation at higher altitudes is greater. Annual ablation at the terminus of White Glacier ranges between 2000 and 4000 mm w.e. a^{-1}. There is now evidence that the retreat of the terminus, previously about 5 m a^{-1}, is decelerating. However, the advance of Thompson Glacier continues. The terminuses of the two glaciers have been in contact since at least the time of the earliest photographs in 1948, but, while the two terminuses remain distinguishable, White Glacier has become a tributary of Thompson Glacier.

The cumulative mass balance of White Glacier from 1959/60 to 2006/07, with due allowance for three missing years, is −7280 mm w.e. The mass balance for 2005/06, at −93 mm w.e., was slightly negative, but not distinguishable from a state of equilibrium given the uncertainty (±200 to 250 mm w.e.) of the measurement. The mass balance normal for 1960–1991 is −95 mm w.e., also slightly negative but in this case significantly so because it is an average of 29 annual measurements. In contrast to that of 2005/06, the balance for 2006/07, −818 mm w.e., was the most negative ever measured, although it is not statistically distinct from the previous record of −781 mm w.e. in 1961/62. 2006/07 was the first balance year in the history of the measurement programme for which missing stake corrections were necessary. For example, in the 200–300 m elevation band, five out of seven stakes melted out. This may be an omen.

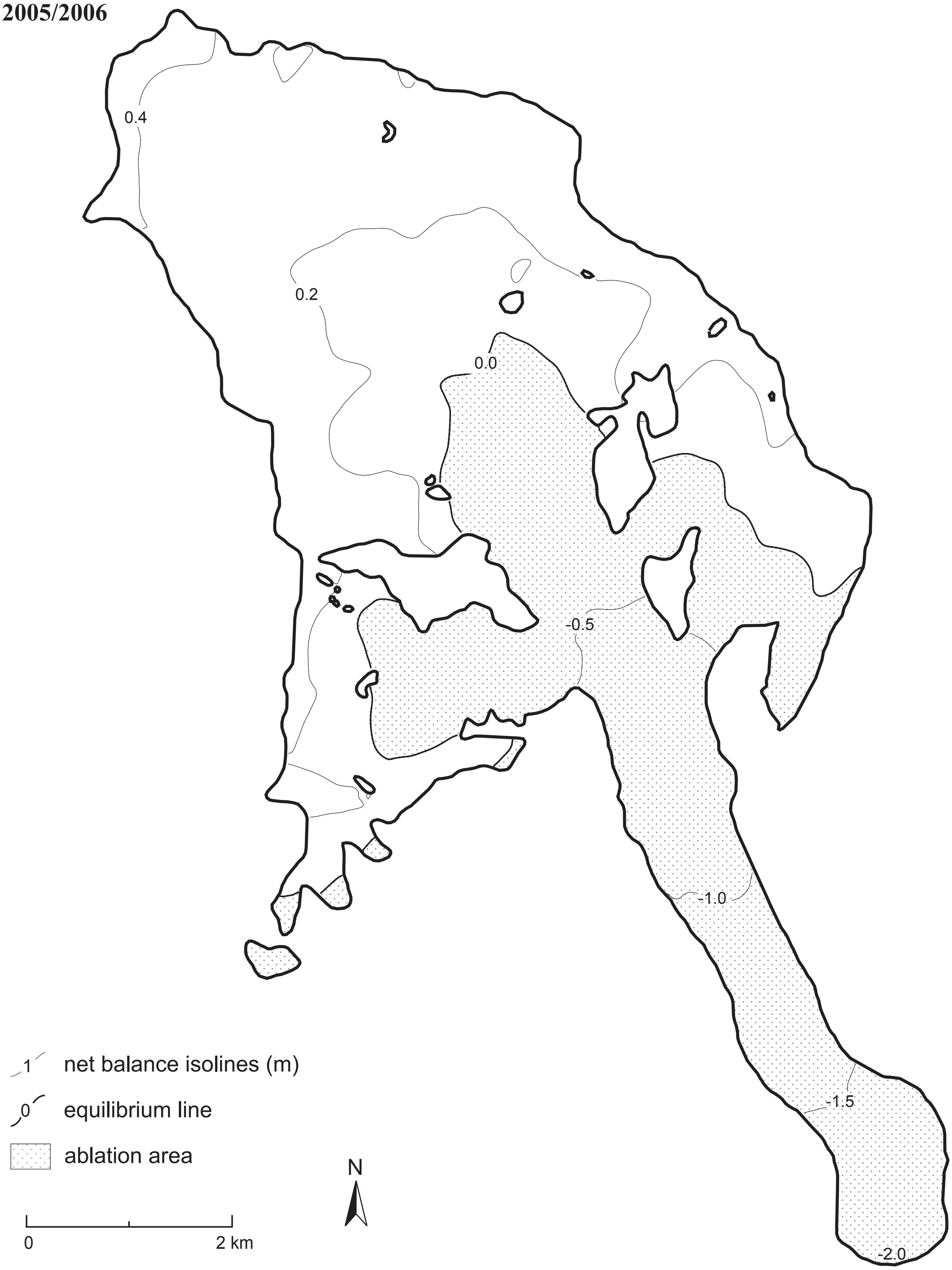
3.5.1 Topography and observation network



White (CANADA)

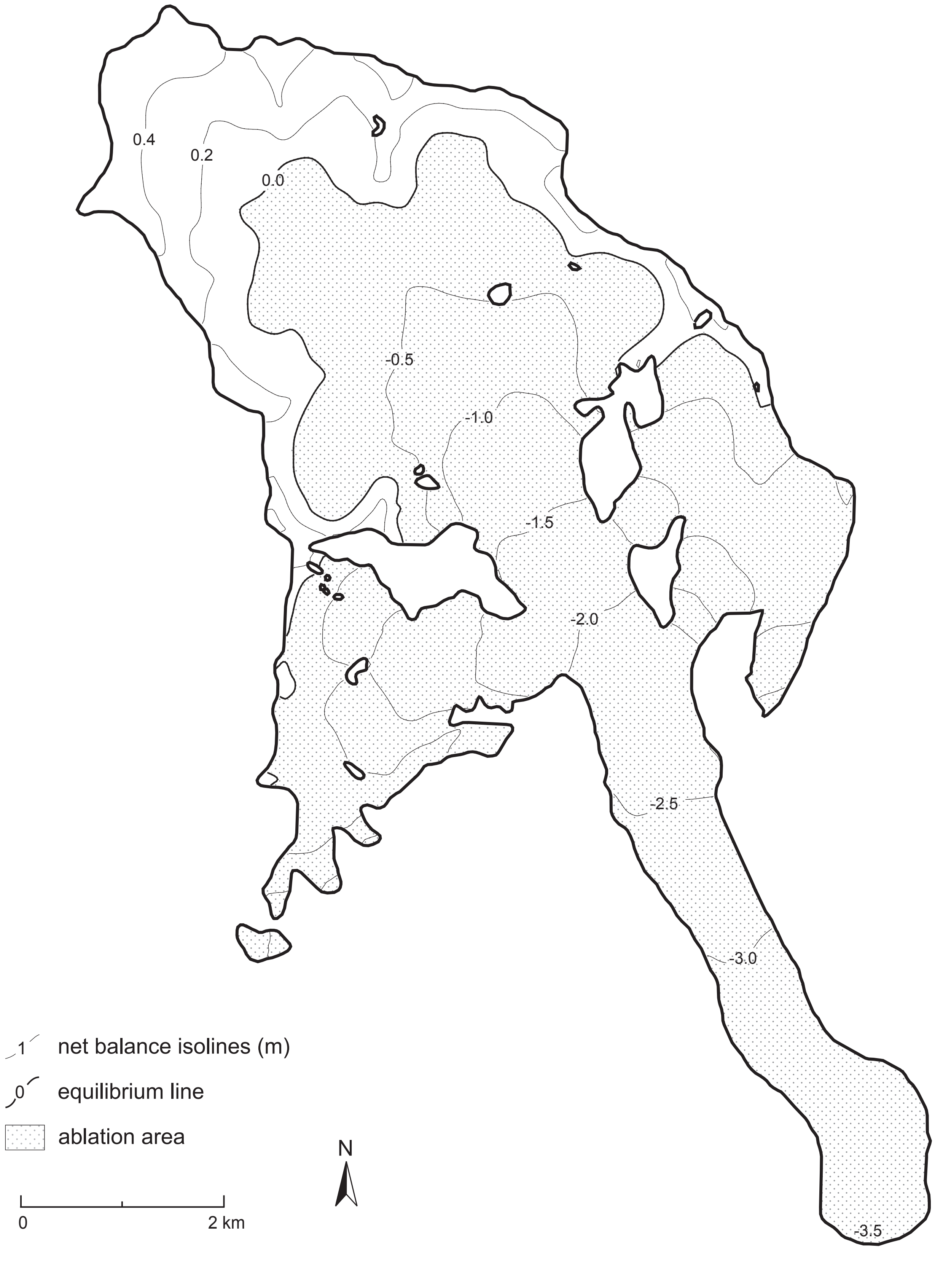
3.5.2 Net balance maps 2005/2006 and 2006/2007

2005/2006



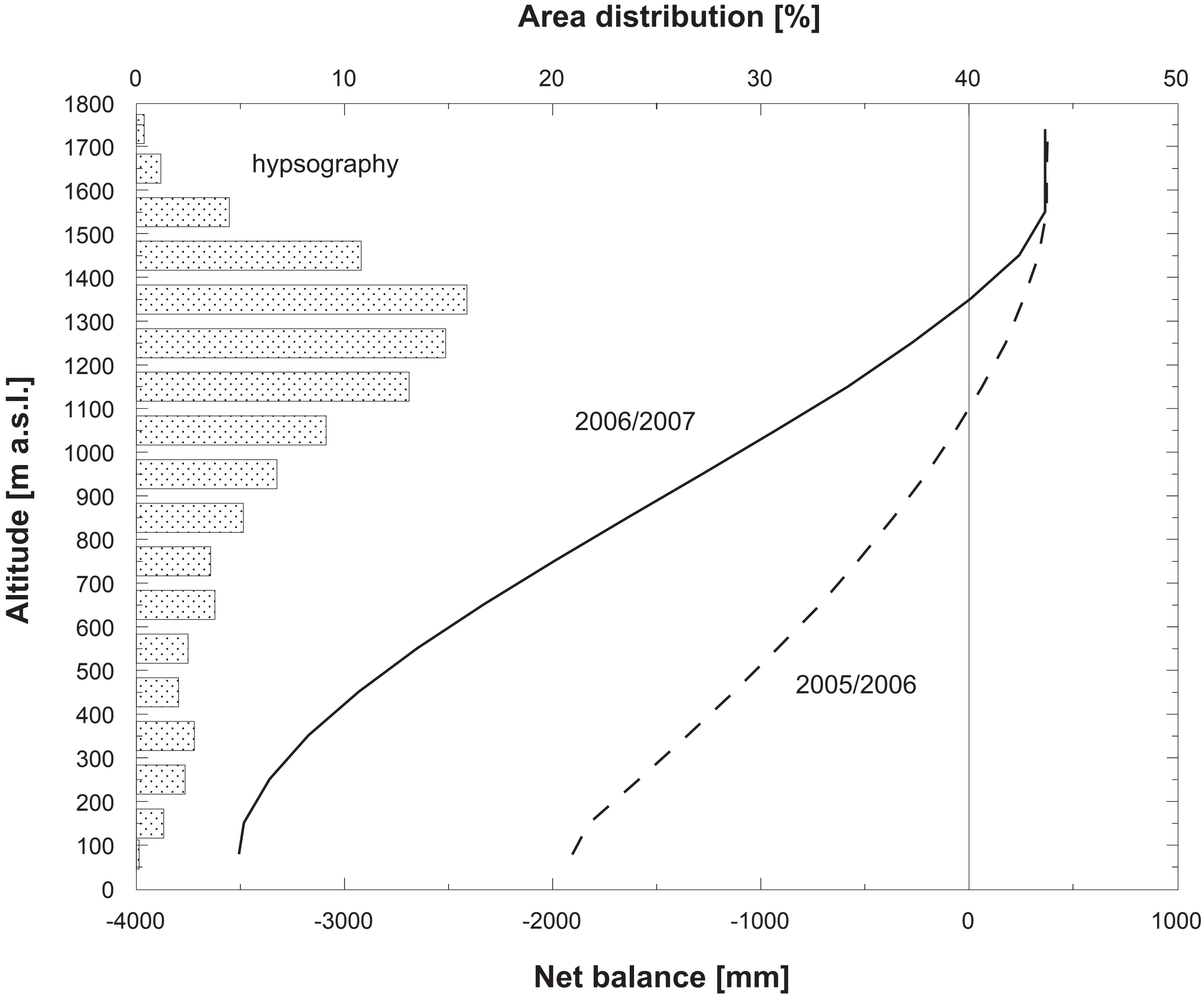
White (CANADA)

2006/2007

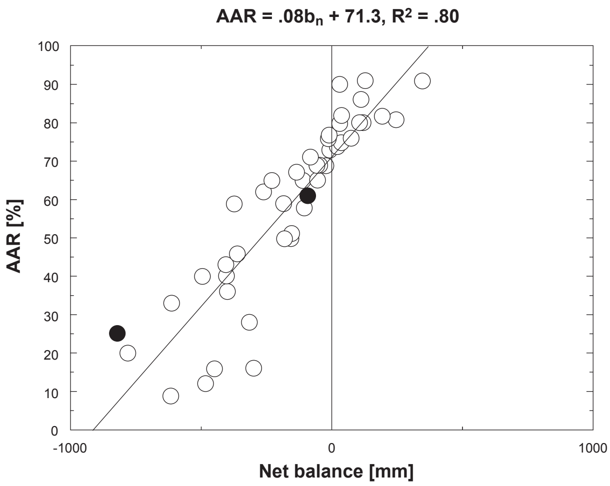


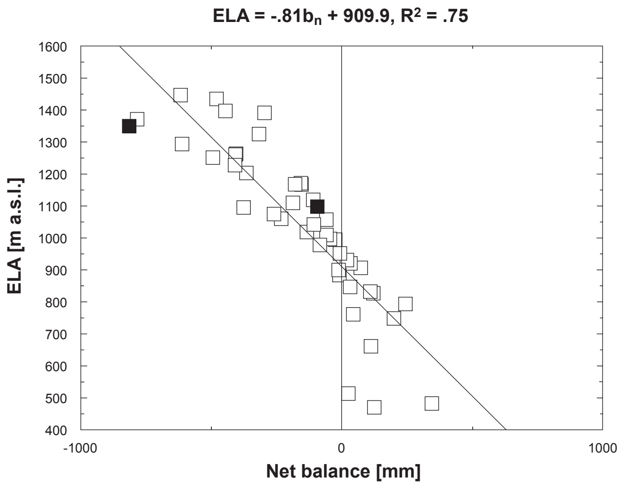
White (CANADA)

3.5.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.5.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





White (CANADA)

3.6 URUMQIHE S. NO 1 (CHINA/TIEN SHAN)

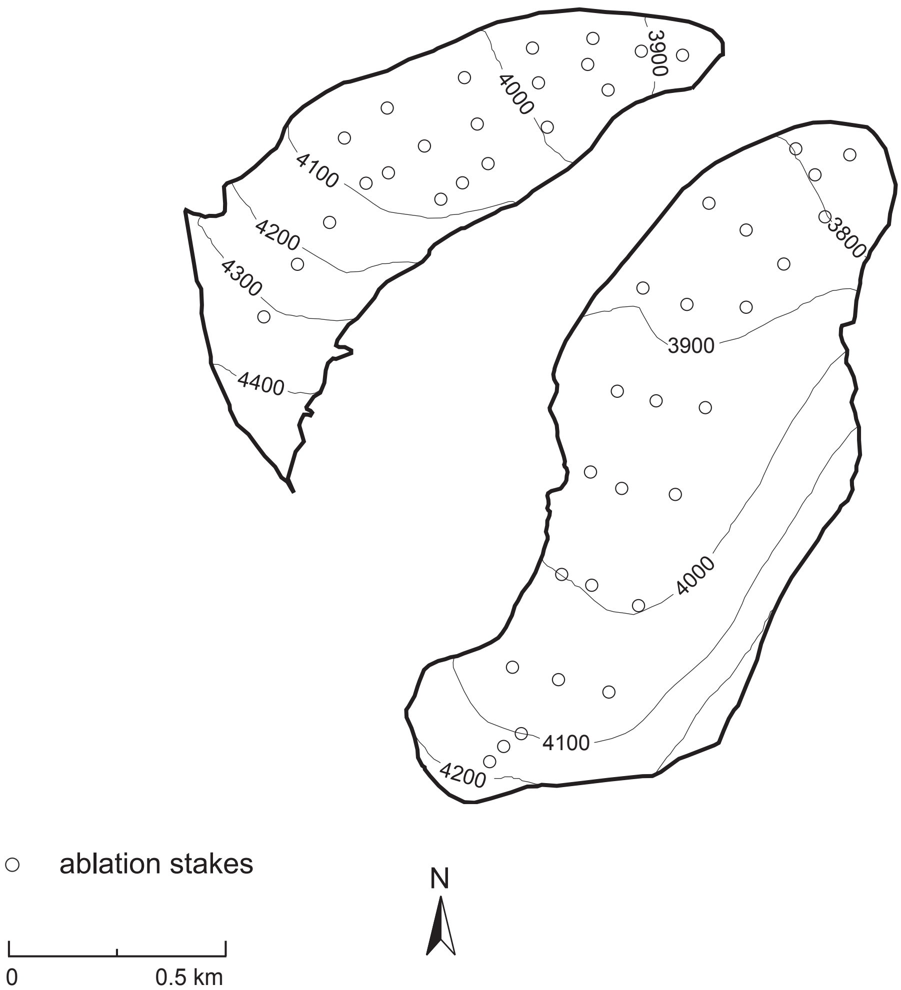
COORDINATES: 43.08 N / 86.82 E

Photo taken by T. Bolch, 2006.

Due to continued glacier shrinkage, the two branches of the former glacier have become two separated small glaciers but are still called East and West branch of Glacier No. 1. The East branch has a total area of 1.1 km^2, the highest and lowest points are at 4267 m and 3742 m a.s.l.; the West branch has a total area of 0.7 km^2, the highest and lowest points are at 4486 m and 3825 m a.s.l. Average annual precipitation measured at the nearby meteorological station at 3539 m a.s.l. is 400 to 500 mm and 600 to 700 mm at the glacier. Mean annual air temperature at the equilibrium line (4022 m a.s.l. for balance years) is estimated at −8.0 to −9.0 °C. The predominantly cold glacier is surrounded by continuous permafrost but reaches melting temperatures over wide areas of the bed. Accumulation and ablation both take place primarily during the warm season and the formation of superimposed ice on this continental-type glacier is important. Since August 2001, a 1:5000 topographic map of the glacier and its forefield has been available for further analysis.

In 2005/06, the mass balance was −920 mm w.e. for the East branch and −506 mm w.e. for the West branch. In 2006/07 , the corresponding values are −696 mm w.e. for the East branch and −542 mm w.e. for the West branch. The calculated mass balance for the entire glacier was −774 mm w.e. in 2005/06 and –642 mm w.e. in 2006/07.

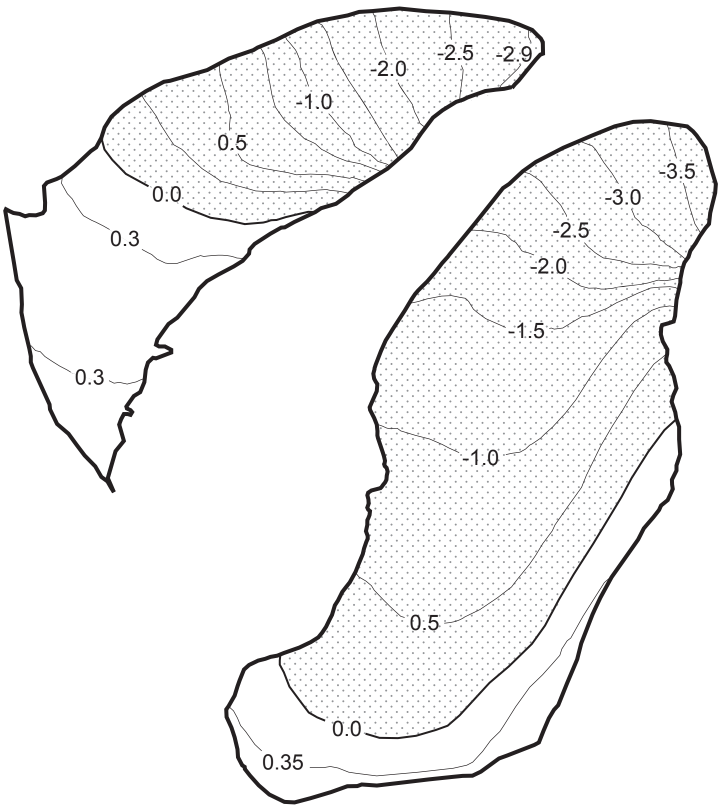
3.6.1 Topography and observation network



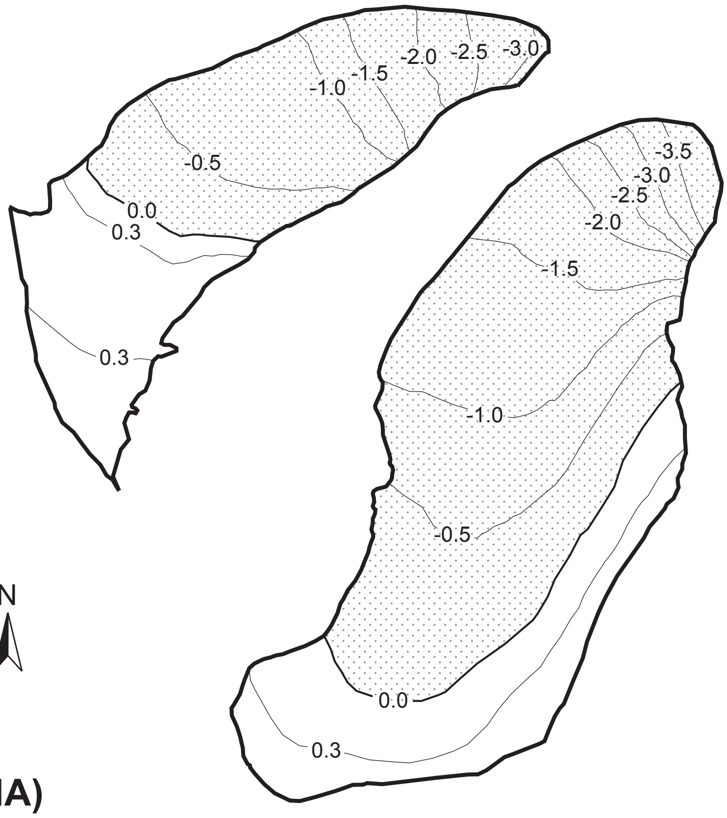
Urumqihe S. No. 1 (CHINA)

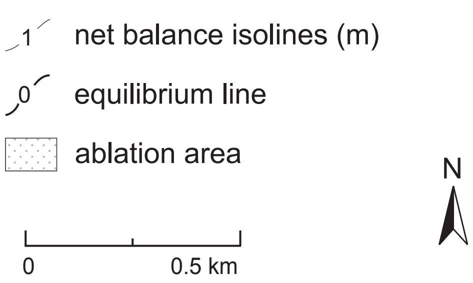
3.6.2 Net balance maps 2005/2006 and 2006/2007

2005/2006



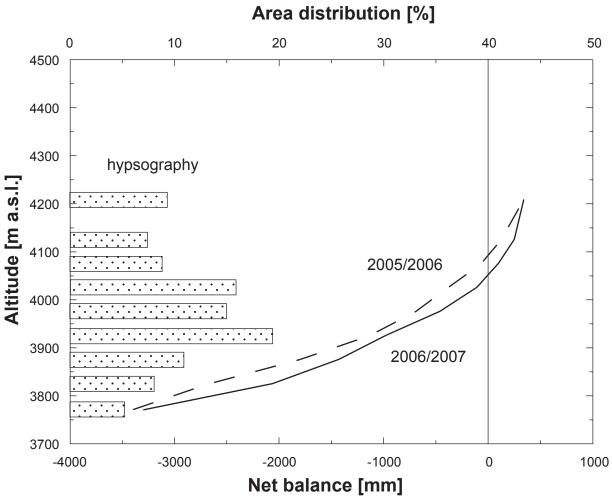
2006/2007



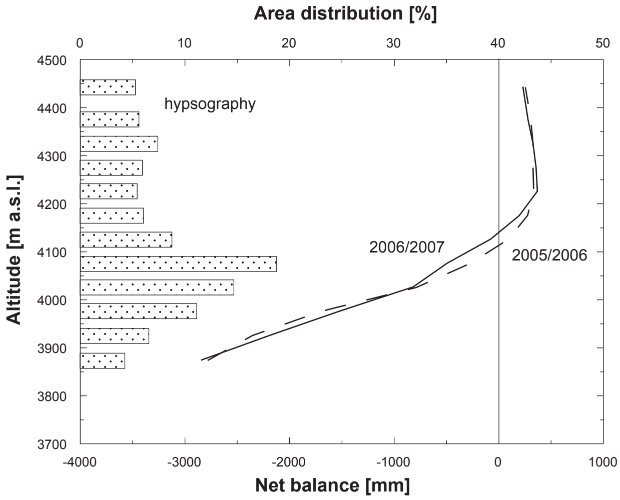


Urumqihe S. No. 1 (CHINA)

3.6.3 Net balance versus altitude (2005/2006 and 2006/2007) of the two branches

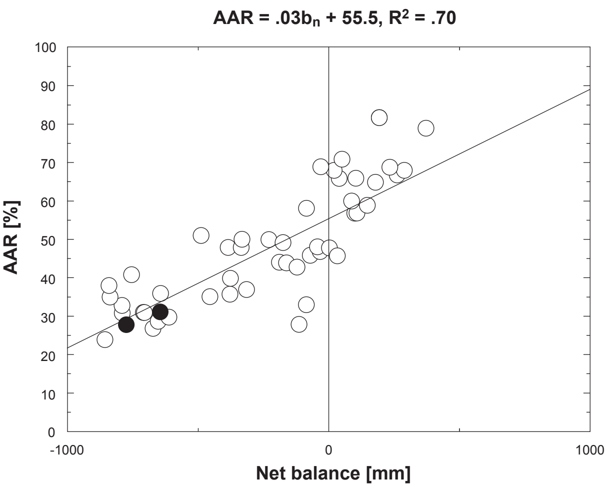


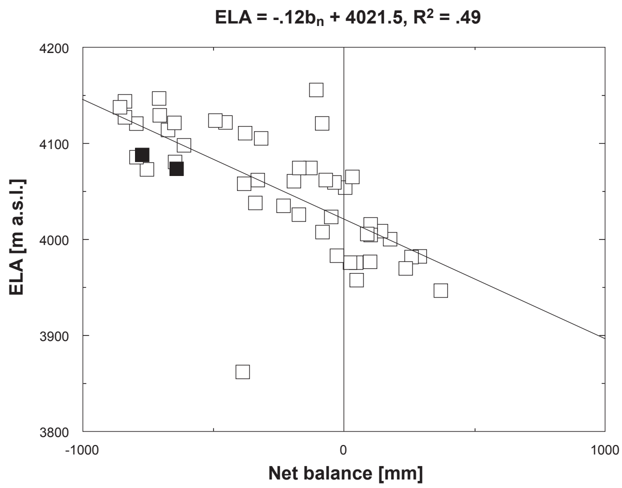
Urumqihe East Branch



Urumqihe West Branch

3.6.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





3.7 ANTIZANA 15 ALPHA (ECUADOR/EASTERN CORDILLERA)

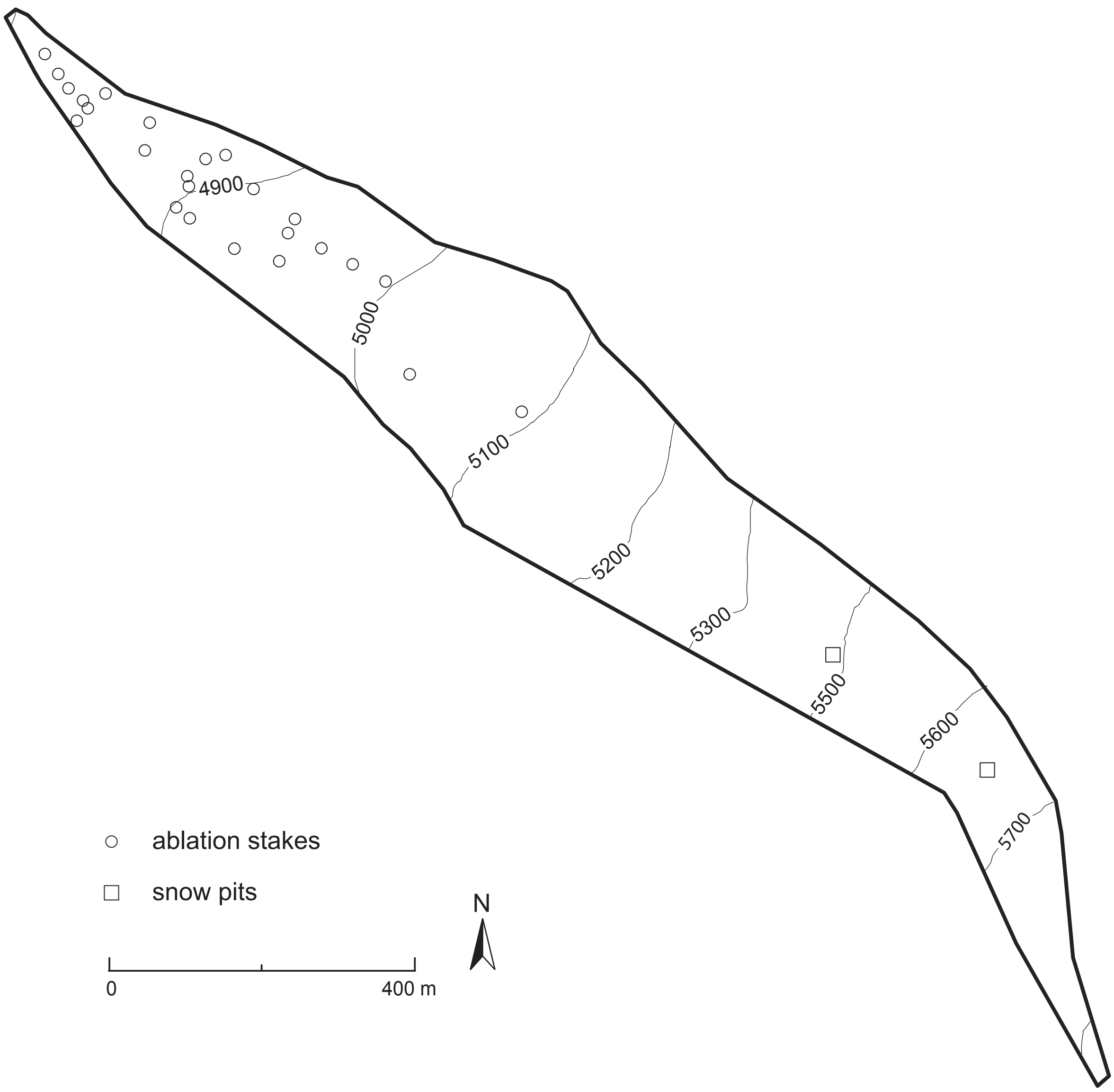
COORDINATES: 0.47 S / 78.15 W

Photo taken by B. Cáceres, January 2008.

The 15 Alpha glacier of Antizana (5760 m – 4852 m a.s.l., 0.27 km^2) is the only one situated near the equator in South America providing regular mass balance information to the scientific community. The surface elevations of the glacier have been determined using aerial photogrammetry from the years 1956 and 1997. The first stakes were placed in 1994 to undertake direct measurements in the terminal zone of the glacier. The main exposition of the glacier is to the west and its length is 1.8 km. During the last thirteen years a mean annual average precipitation of 925 mm a^{-1} was measured. In the year 2006/07 a mean annual air temperature of 1.2 °C was recorded at the nearby meteorological station (4820 m a.s.l.), with an annual average of 1.5 °C since 2001.

The 15 Alpha glacier had an average annual mass balance of −615 mm w.e. a^{-1} since 1995. The interannual variation is highly variable. Negative balances were observed during most of the years. Negative records were measured in the years 1995 to 2007. The negative mass balance series was interrupted by two positive balance years in 1999 and 2000. The years 2005/06 and 2006/07 had a negative balance with values of −452 mm w.e. and −658 mm w.e., respectively. The variability of the ENSO (El Niño Southern Oscillation) has been an important factor affecting the climatic conditions and their resulting influence on the mass balance evolution of the Ecuadorian glaciers. Years with favorable conditions for the Ecuadorian glaciers seem to be related to La Niña (cold) events, and for unfavorable conditions to El Niño (warm) events.

3.7.1 Topography and observation network

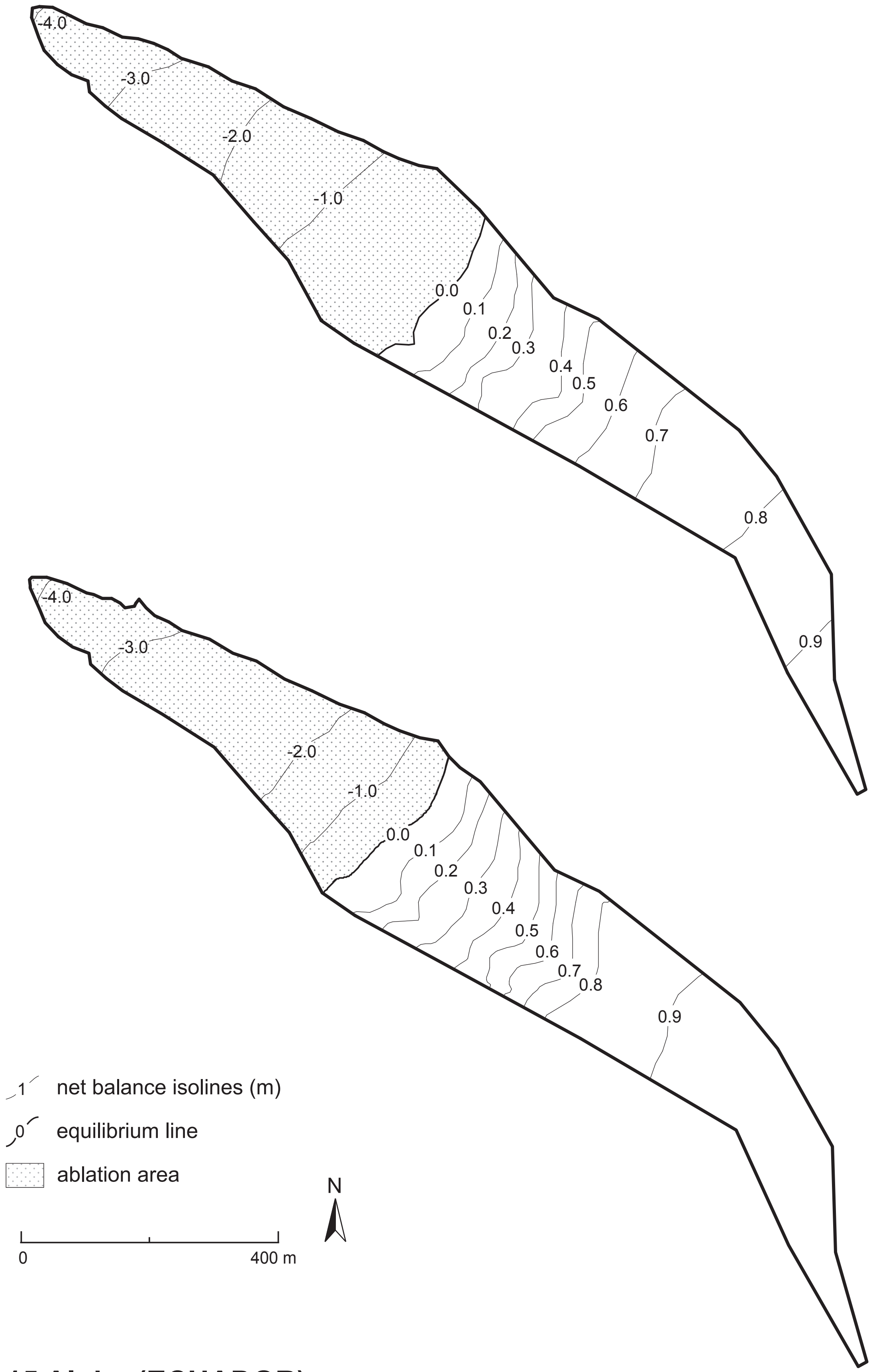


Antizana 15 Alpha (ECUADOR)

3.7.2 Net balance maps 2005/2006 and 2006/2007

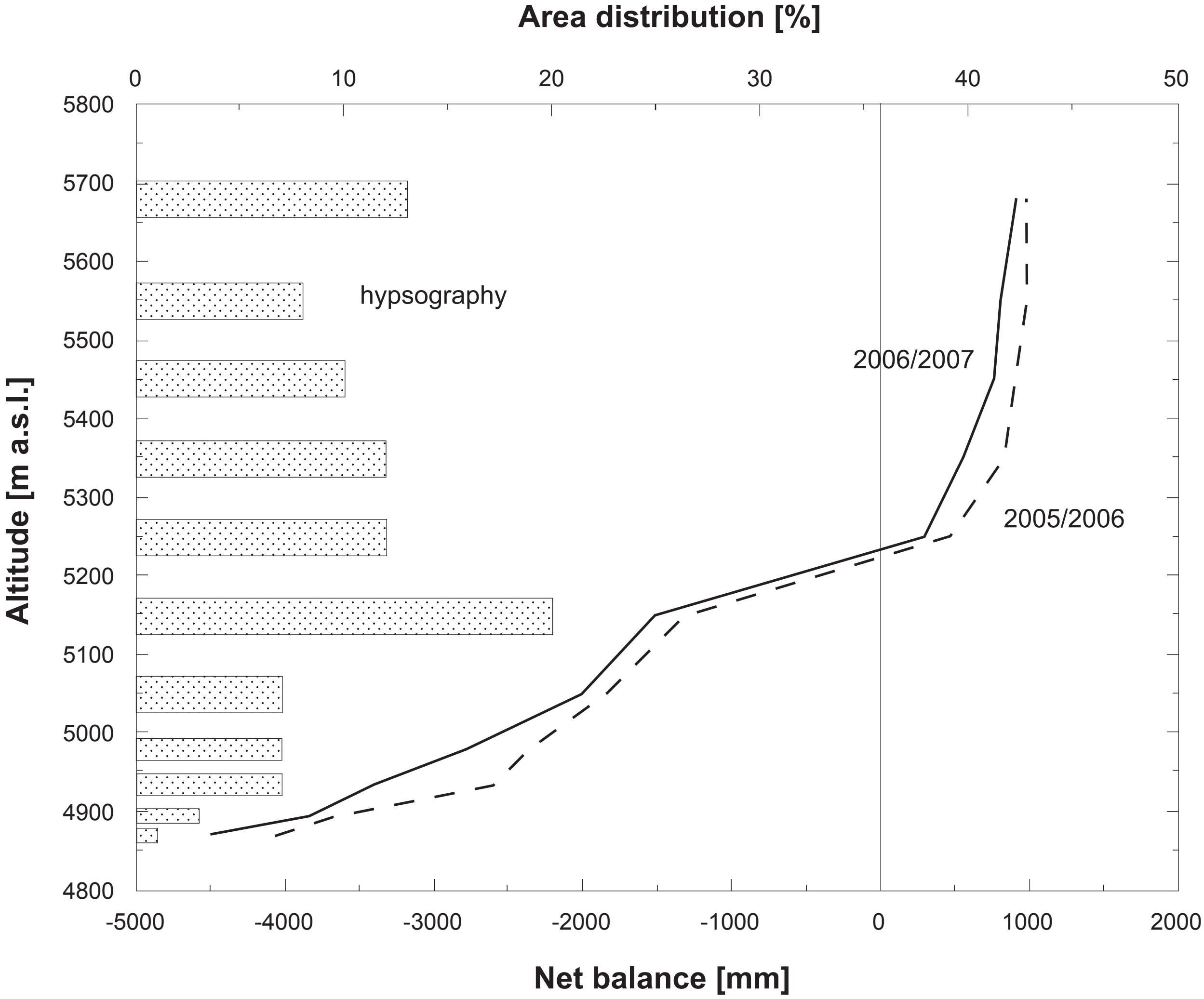
2005/2006

2006/2007

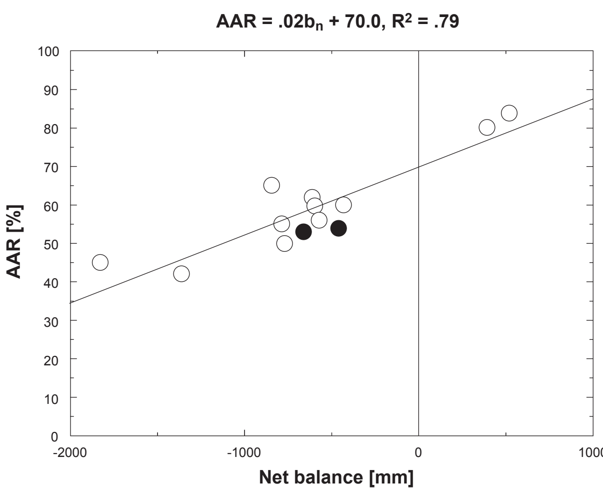


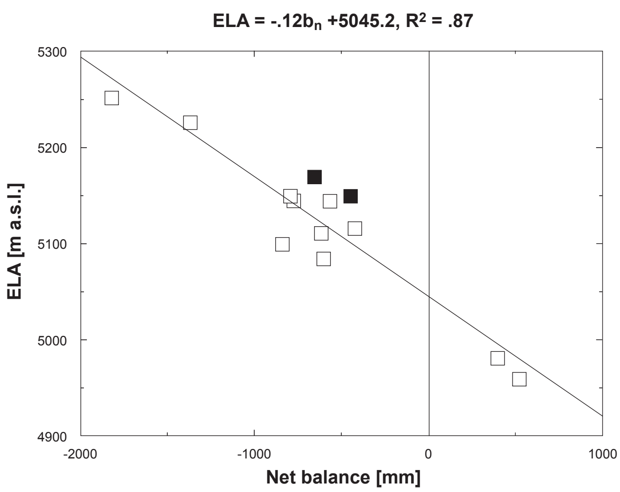
Antizana 15 Alpha (ECUADOR)

3.7.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.7.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





Antizana 15 Alpha (ECUADOR)

3.8 CARESÈR (ITALY/CENTRAL ALPS)

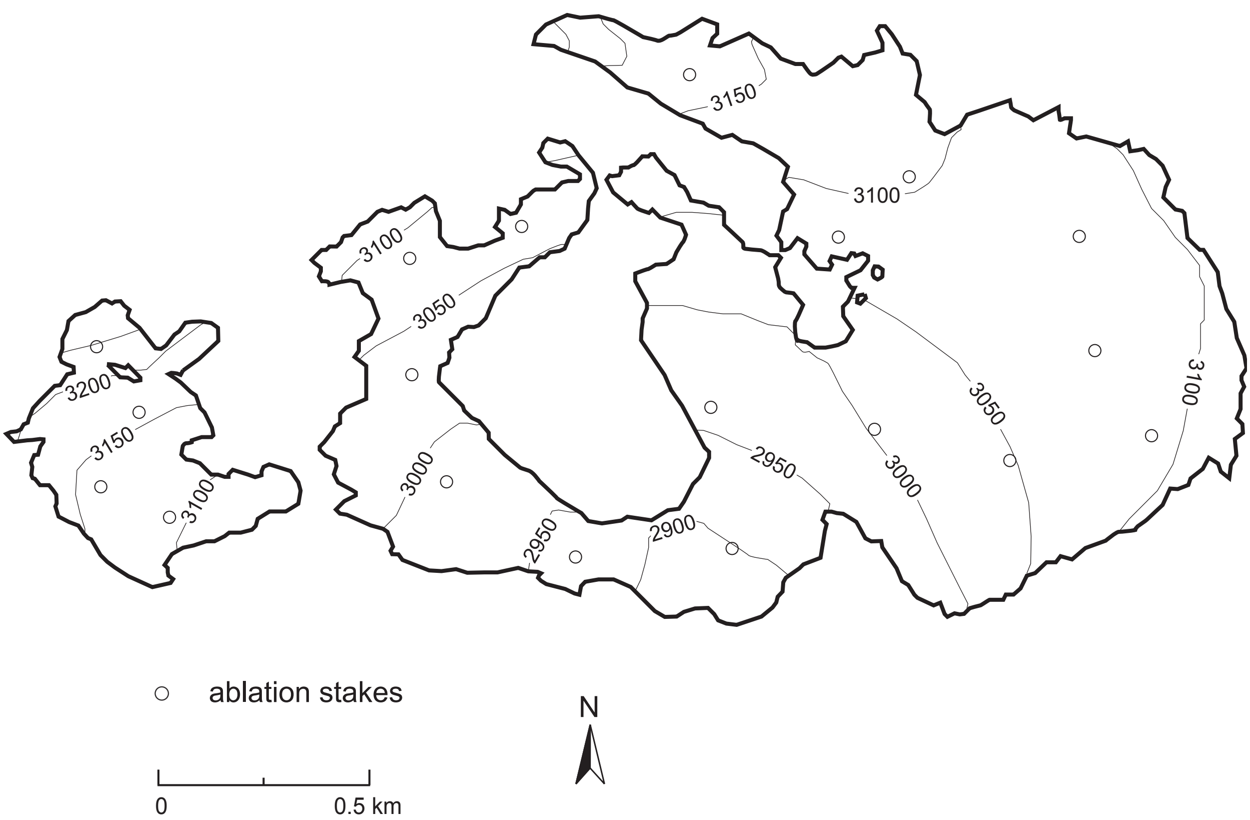
COORDINATES: 46.45 N / 10.70 E

Photo taken by L. Carturan on 31st of August 2007.

Caresèr Glacier is located in the eastern sector of Ortles-Cevedale group (European Alps, Italy). It occupies an area of 2.4 km^2 and extends from 3279 m to 2869 m a.s.l. The surface is mainly exposed to the south and is quite flat. 75 % of the glacier area lies between 2900 m and 3100 m a.s.l. and the median altitude is 3069 m a.s.l. The mean annual air temperature at this elevation is about −3 to −4 °C and precipitation averages 1450 mm, of which 80 % falls as snow. The mass balance investigations on Caresèr Glacier began in 1967 and extend until present without interruption. The glacier mass balance was near to equilibrium until 1980, but since then it has shown strong mass losses. The mean value of the annual mass balance was −1200 mm w.e. from 1981 to 2002, but decreased to −2350 mm w.e. from 2003 to 2007. This is a result of both warmer ablation seasons and positive feedbacks (albedo and surface lowering). The repeated negative mass balances are causing huge changes in the glacier morphology, with widespread bedrock emersion and rapid fragmentation. The most remarkable event was the detachment of the western portion of the glacier from the main ice body in 2005.

During the hydrological years 2005/06 and 2006/07 the mass balance of Caresèr glacier was strongly negative, reaching the 4th and the 2nd worst values of the entire series of observations with −2093 and −2745 mm w.e., respectively. Warm and long ablation seasons played a dominant role in the observed balance behaviour, but in 2006/07 the winter precipitation was also extremely scarce (40 % of the long-term mean), and ice ablation started abnormally by the end of June.

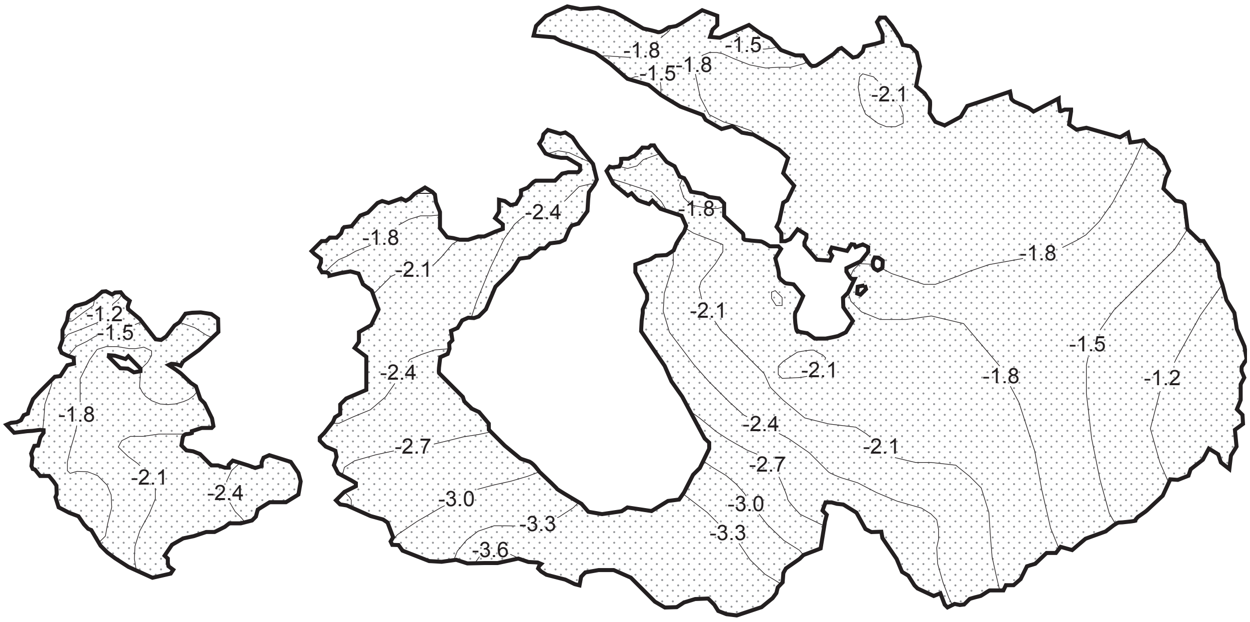
3.8.1 Topography and observation network

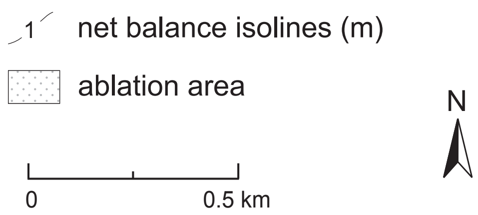


Caresèr (ITALY)

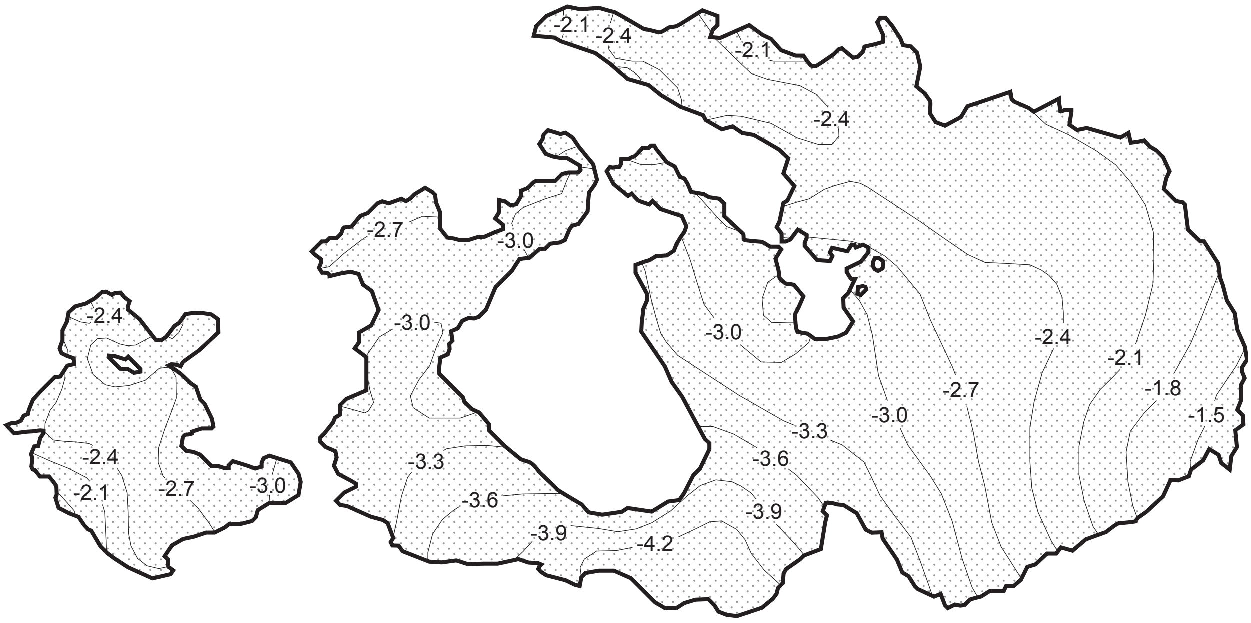
3.8.2 Net balance maps 2005/2006 and 2006/2007

2005/2006



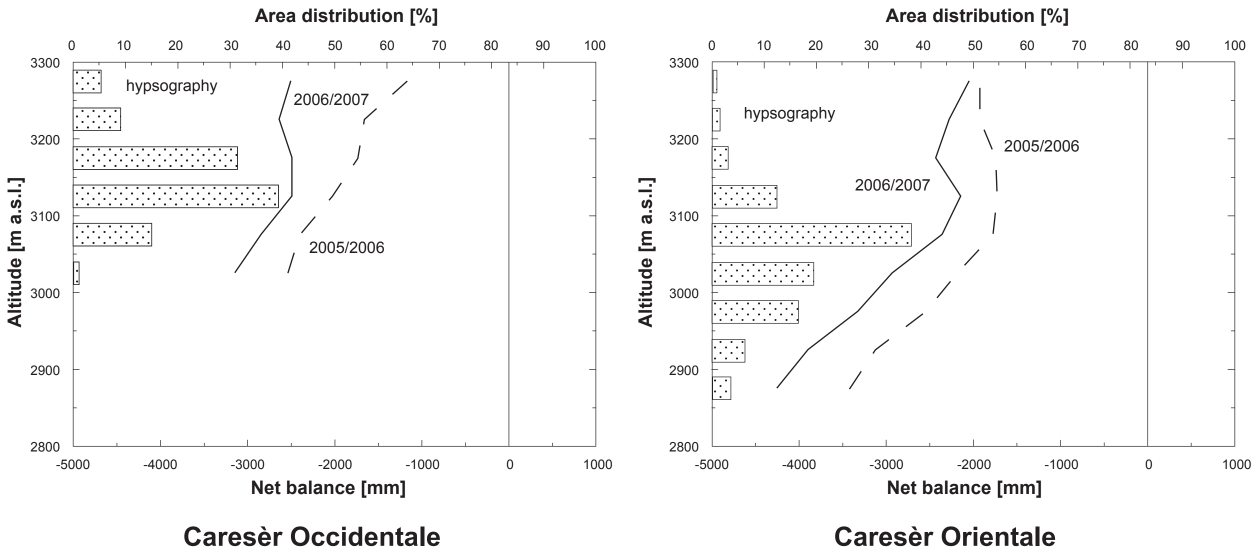


2006/2007

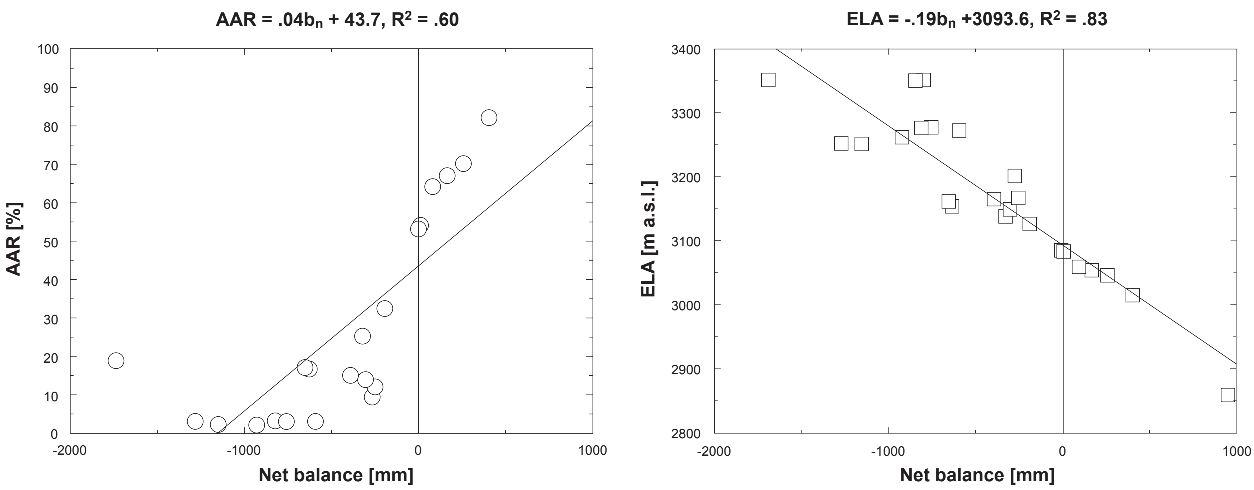


Caresèr (ITALY)

3.8.3 Net balance versus altitude (2005/2006 and 2006/2007) for both parts of the glacier



3.8.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period



3.9 MALAVALLE (ITALY/CENTRAL ALPS)

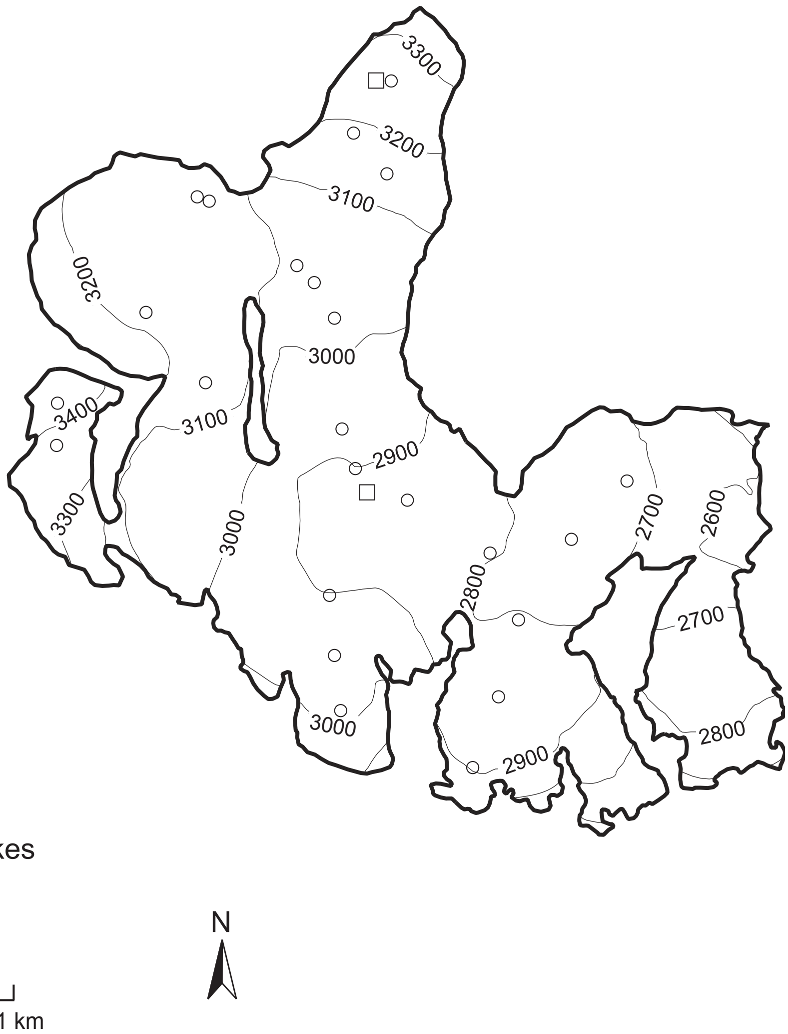
COORDINATES: 46.95 N / 11.12 E

Photo taken by M. Kuhn, 22nd September 2007.

The Malavalle Glacier (Übeltalferner) is the widest in the Breonie Alps, an alpine ridge in the Stubai Alps lying in the Italian territory along the Austrian border. The head of the Val Ridanna is shaped like a wide bowl with several levels with different-shaped cirques presenting varying accumulation conditions, depending on aspect and slope. The glacier arms extend from all these cirques and flow into the wide central stream at about 2900 m a.s.l. The front moves down to 2530 m a.s.l. The left side of the glacier stretches along the moraine, which developed between the end of the 18th and the beginning of the 19th century, and ends at a small proglacial lake at about 2500 m a.s.l. The main stream (Fernerbach) originates at the right border of the front, which is on a step above a 300 m drop.

The mass balance measurements began in the year 2001/02, using the fixed date method. In the first three years, the measurements were done annually, and since 2004/05 they have been done on a seasonal basis. In the years 2005/06 and 2006/07, severe mass losses of −1322 mm w.e. and −1358 mm w.e. were measured, respectively. The average mass loss over the six-year period was −1010 mm w.e., resulting in a total ice loss of 6058 mm w.e.. The continuous retreat of the glacier affects both its extension and volume. At the end of the summer season, a new topographic survey was carried out by GPS in order to update the glacial border in the front area, where a 0.4 km^2 tributary glacier is expected to detach in the near future.

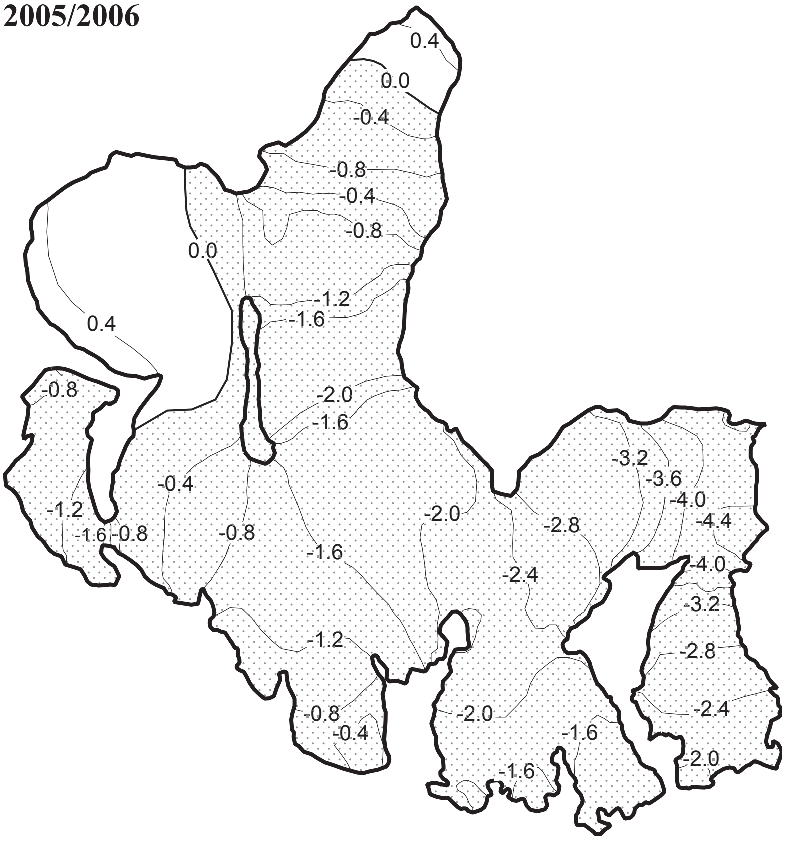
3.9.1 Topography and observation network



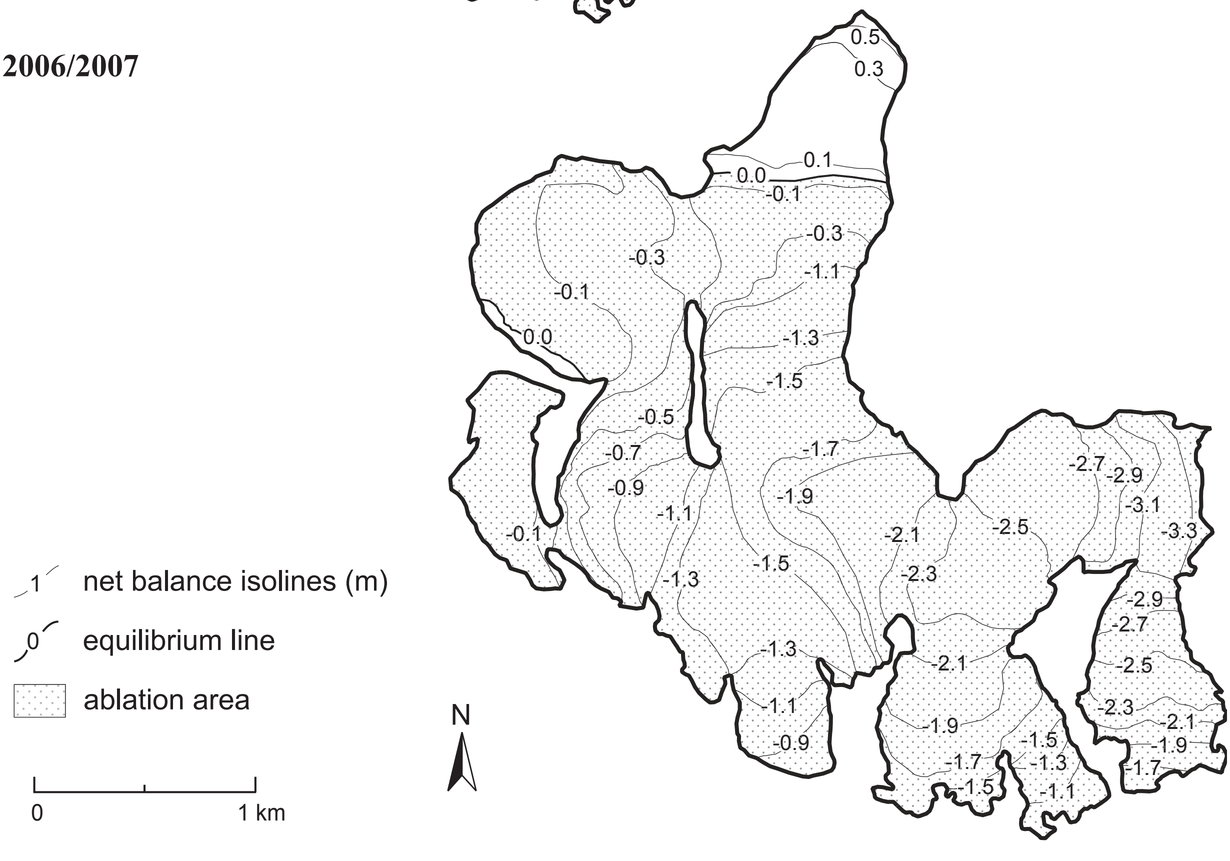
Malavalle (ITALY)

3.9.2 Net balance maps 2005/2006 and 2006/2007

2005/2006

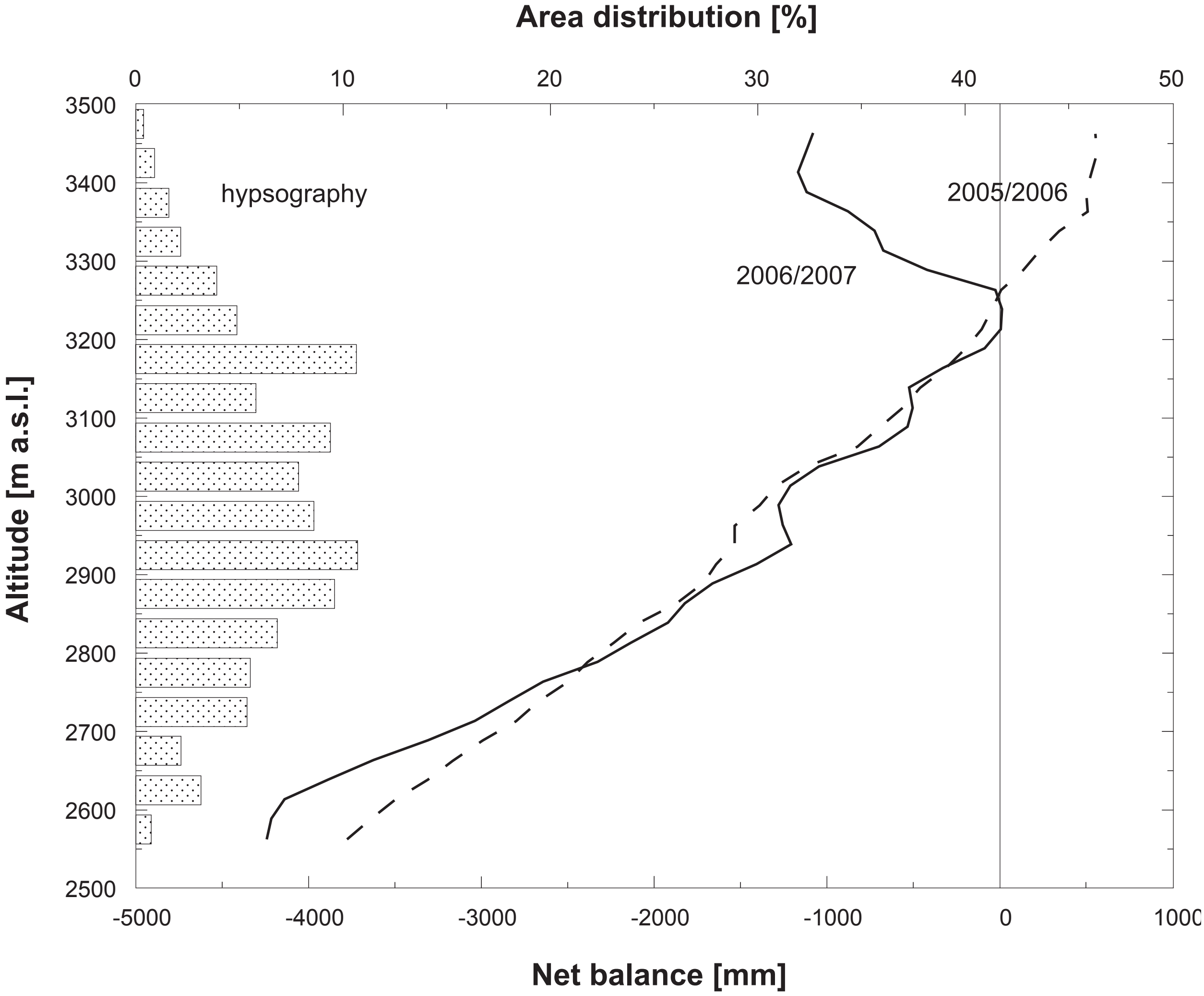


2006/2007

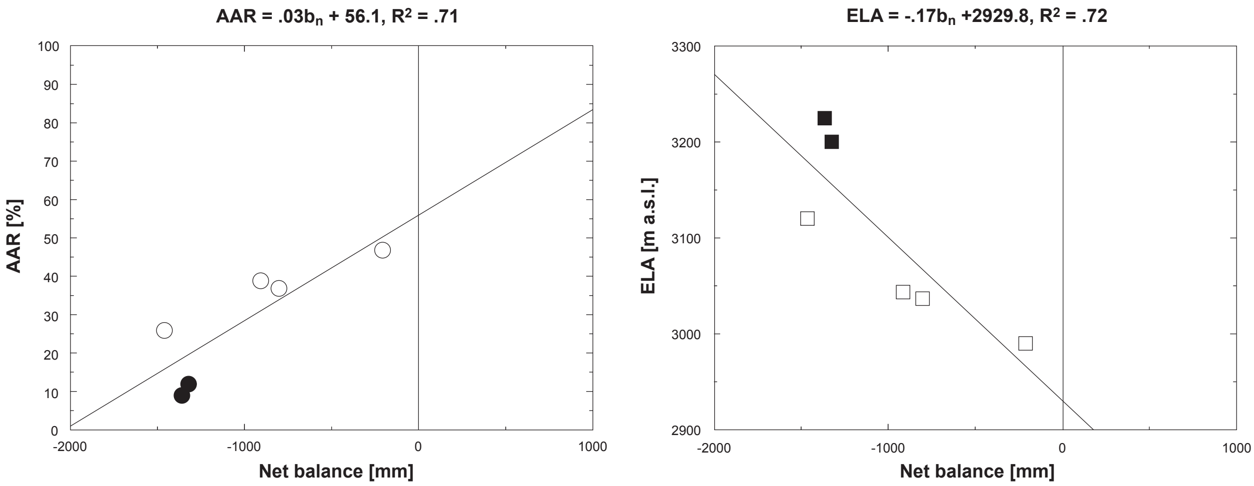


Malavalle (ITALY)

3.9.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.9.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period



Malavalle (ITALY)

3.10 TSENTRALNIY TUYUKSUYSKIY (KAZAKHSTAN/TIEN SHAN)

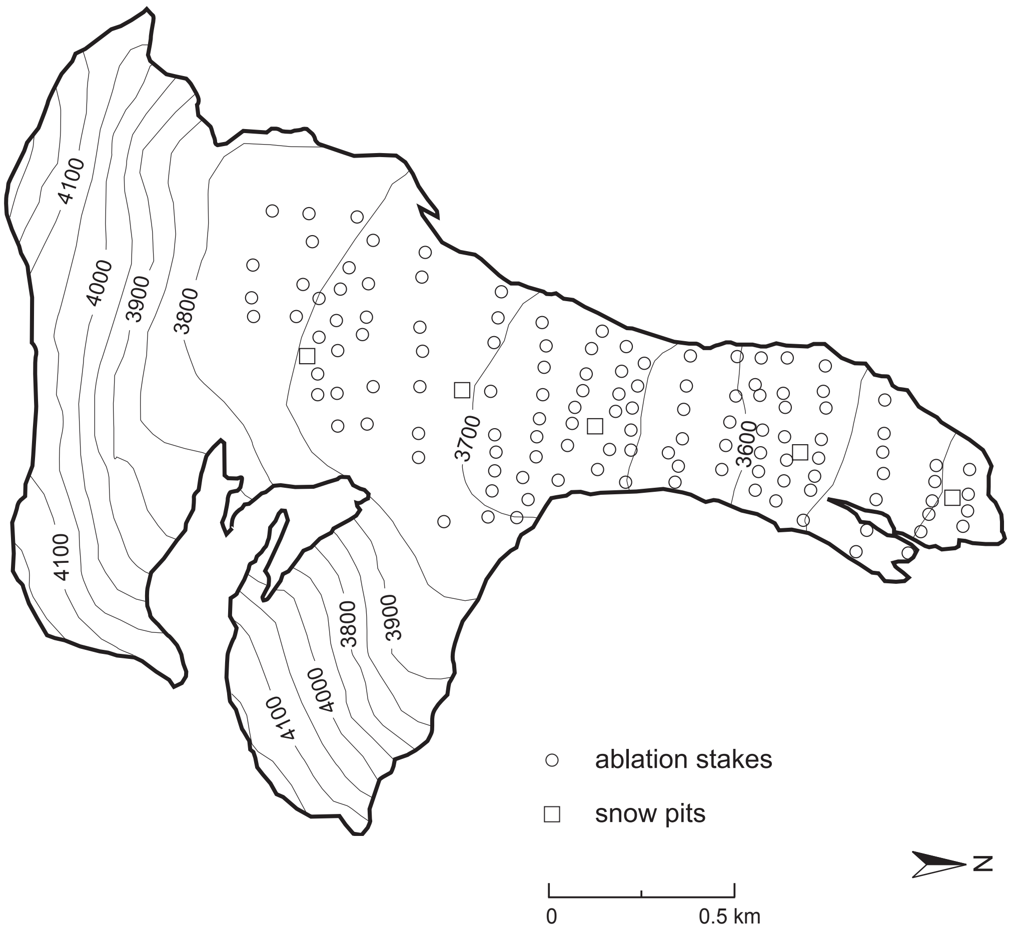
COORDINATES: 43.05 N / 77.08 E

Photo taken by V.P. Blagoveshensky in July 2007.

The valley-type glacier in the Zailiyskiy Alatau Range of Kazakh Tien Shan is also called the Tuyuksu Glacier. It extends from 4200 m to 3425 m a.s.l. and has a surface area of 2.51 km^2 (including debris-covered ice) with exposure to the north. Mean annual air temperature at the equilibrium line of the glacier (around 3980 m a.s.l. in 2006 and 3885 m a.s.l. in 2007 for balanced conditions) is between −6 to –7 ºC. The summer precipitation equals 40 % of the annual sum. A characteristic feature of these highly continental climatic conditions is the stable winter anticyclones. The glacier is considered to be cold to polythermal and surrounded by continuous permafrost.

Average annual precipitation as measured with a great number of precipitation gauges for the balance year 2005/06 is equal to 931 mm and 1074 mm for the balance year 2006/07. The summer season of 2006 was 0.4 ºC warmer than the average value for the period 1971/72–2005/06, while precipitation was equal to average. August was 1.8 ºC warmer than the average value. As a result of these conditions the glacier mass balance in 2006 was −969 mm w.e. The summer season of 2007 was 1.1 °C warmer than the average value for the period 1972–2007, while precipitation was 70 mm more than average. As a result of these conditions the glacier mass balance in 2007 was −915 mm w.e.

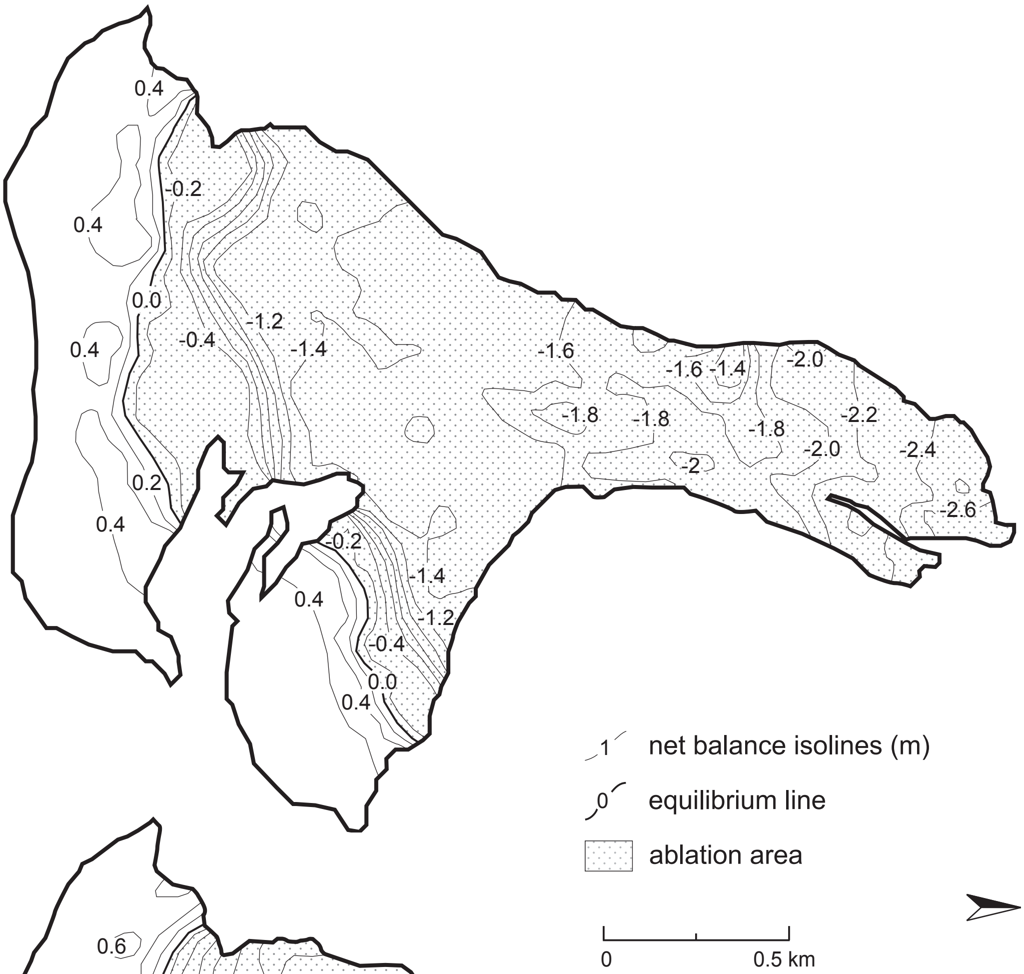
3.10.1 Topography and observation network



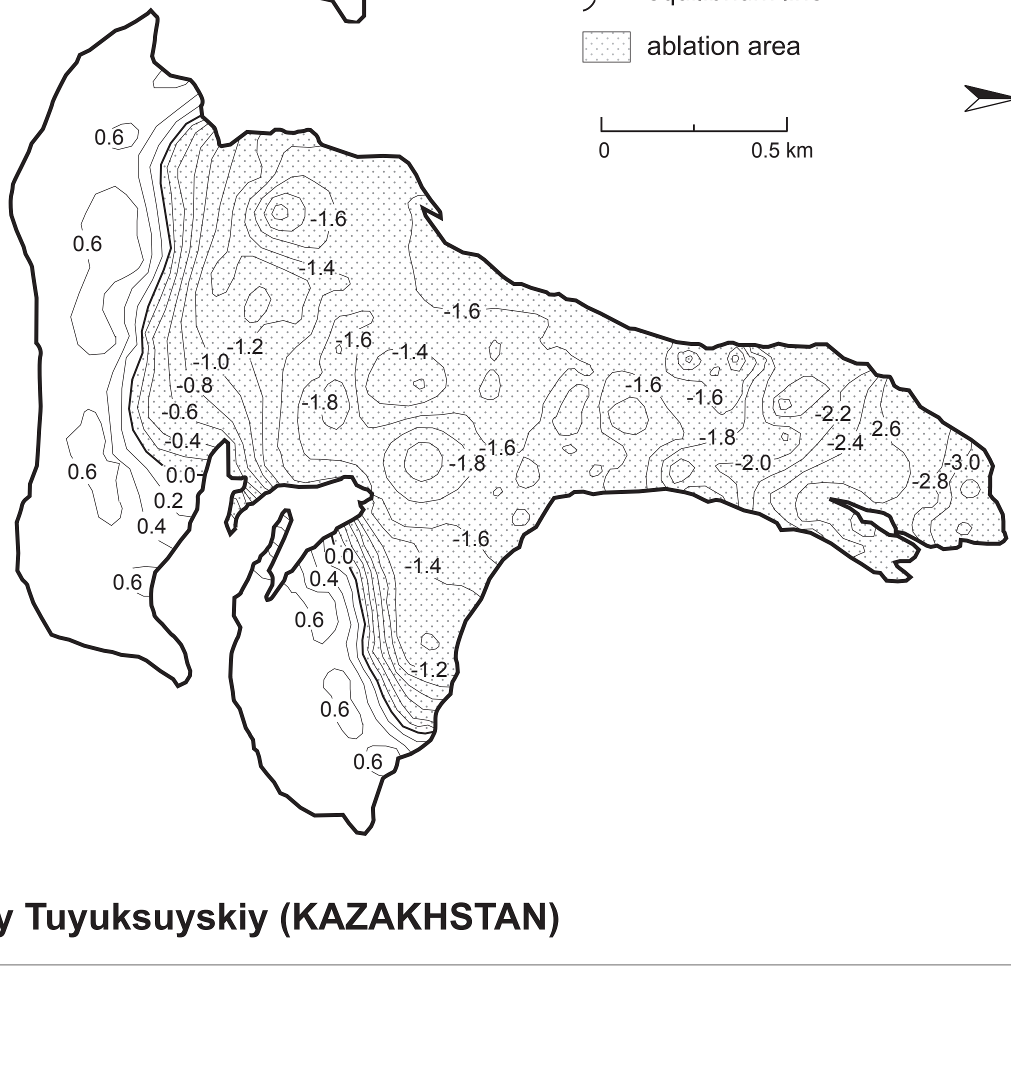
Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

3.10.2 Net balance maps 2005/2006 and 2006/2007

2005/2006

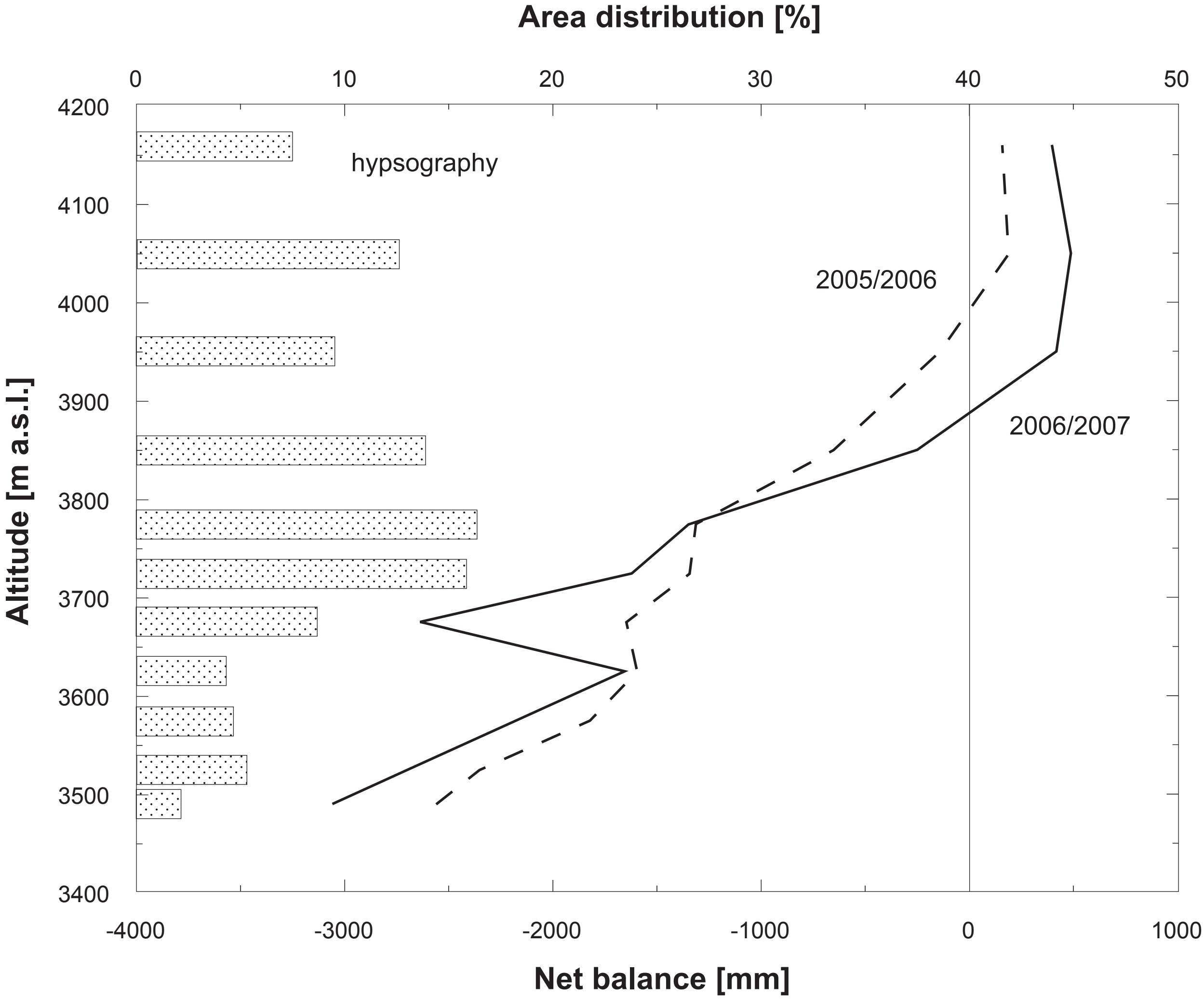


2006/2007

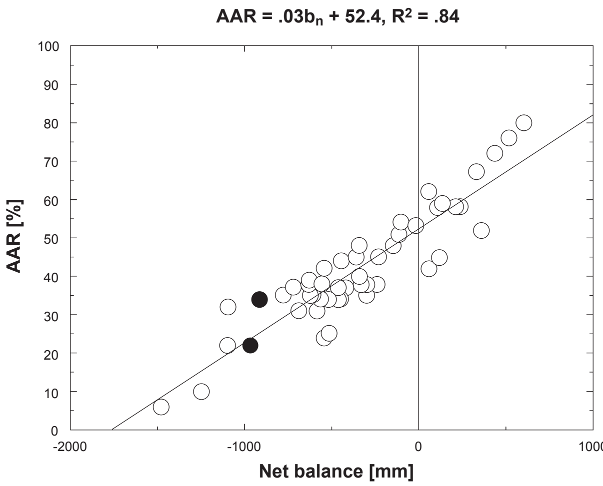


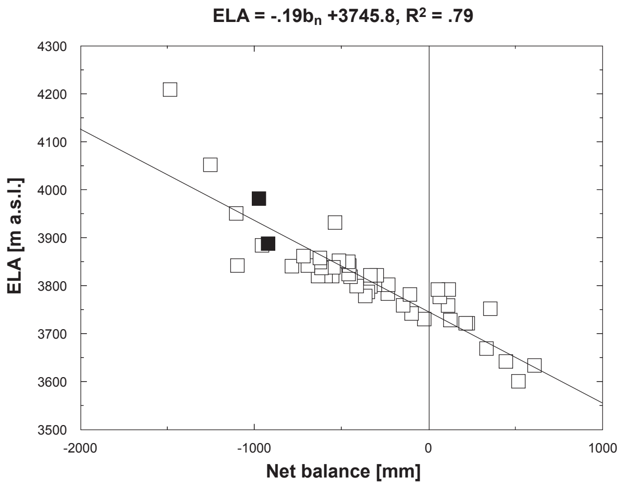
Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

3.10.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.10.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





Tsentralniy Tuyuksuyskiy (KAZAKHSTAN)

3.11 BREWSTER (NEW ZEALAND/TITITEA MT ASPIRING NP)

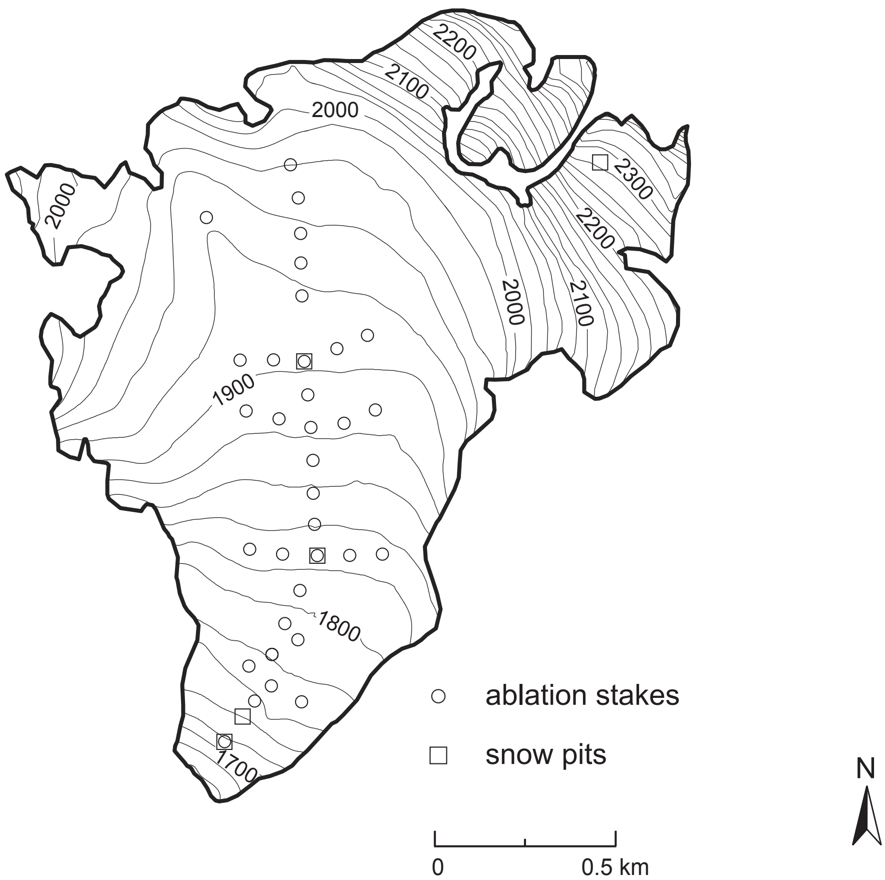
COORDINATES: 44.08 S / 169.44 E

Photo taken by A. Willsman (Glacier Snowline Survey, NIWA), 14 March 2008.

Brewster Glacier is a temperate glacier on the Main Divide of the Southern Alps of New Zealand and lies south of Mt Brewster (2515 m a.s.l.). The glacier has an area of about 2.5 km^2, is about 2.5 km long, and extends over an elevation range of 730 m, from 2390 m to 1660 m a.s.l. The major part of the glacier, up to about 2000 m a.s.l., faces south with an average slope of 11°, and the top 400 m have a south-westerly aspect with a mean slope of 31°. The maximum ice thickness is about 150 m, and a few hundred meters up the snout there is a bed overdeepening. On the western margin of the glacier the valley walls are not clearly confined. The glacier surface is very clean and there is little sedimentation in the glacier forefield. The exposed bedrock is polished and displays abrasion marks from the glacier. These observations, the very few debris delivering rockwalls surrounding Brewster Glacier and very low-frequency measurements by Thiel (1986) suggest minor subglacial sediments, with eroding rather than sedimenting glacier activities. Brewster Glacier is a maritime glacier type with an annual mean precipitation (1951–1980) between 3200–4800 mm and a mean annual air temperature at the ELA (ca. 1900 m a.s.l. for a balanced year) of about 1 °C.

In the years 2005/06 and 2006/07, the mass balances were slightly positive (+282 mm w.e. and +297 mm w.e., respectively) with ELAs at similar altitudes (1893 m a.s.l. and 1899 m a.s.l.). More knowledge about the mass balance above 2000 m a.s.l. and new glacier outlines are needed. Updated glacier outlines would resolve the discrepancies between the mentioned altitude range and the topographical map.

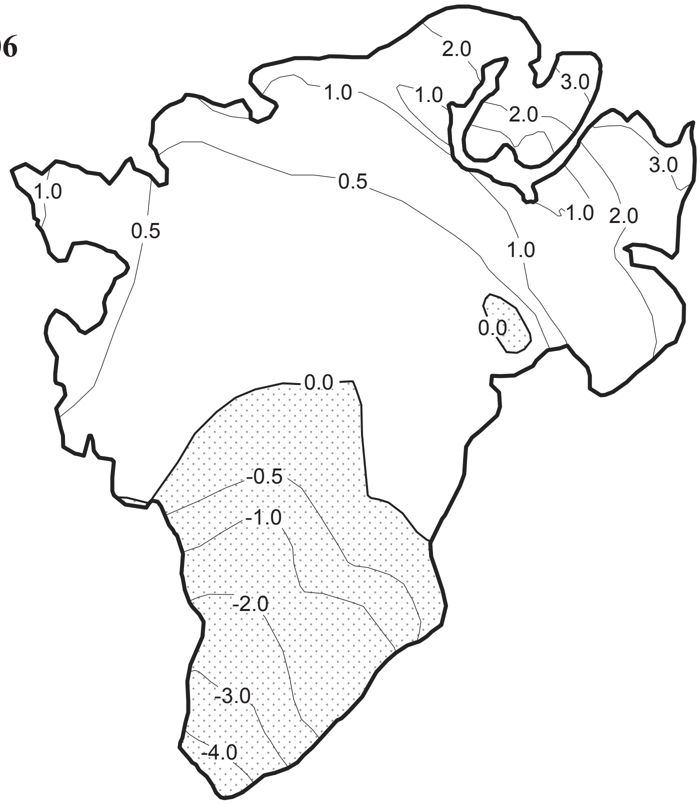
3.11.1 Topography and observation network



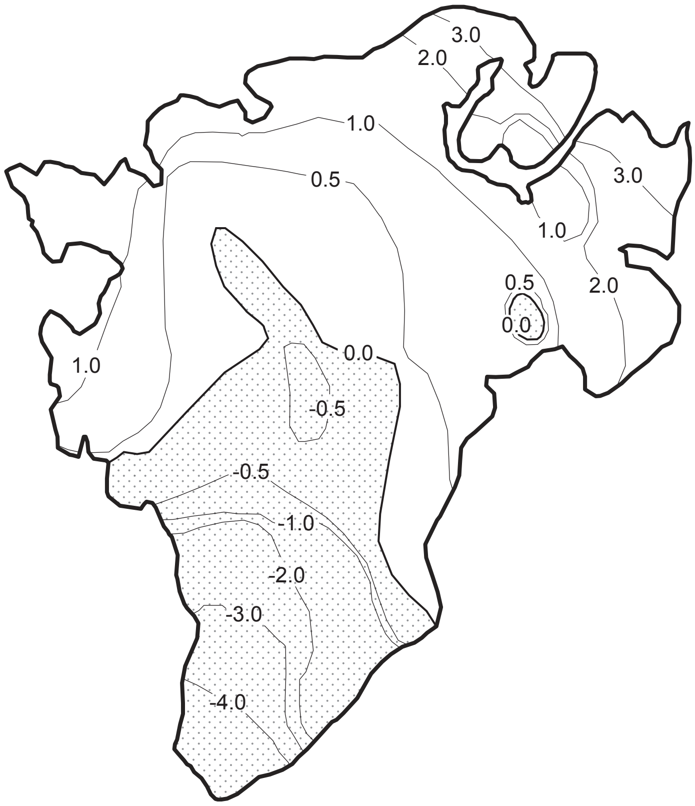
Brewster Glacier (NEW ZEALAND)

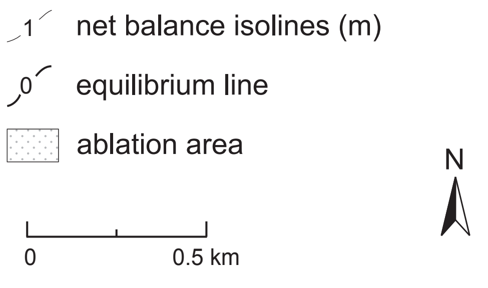
3.11.2 Net balance maps 2005/2006 and 2006/2007

2005/2006



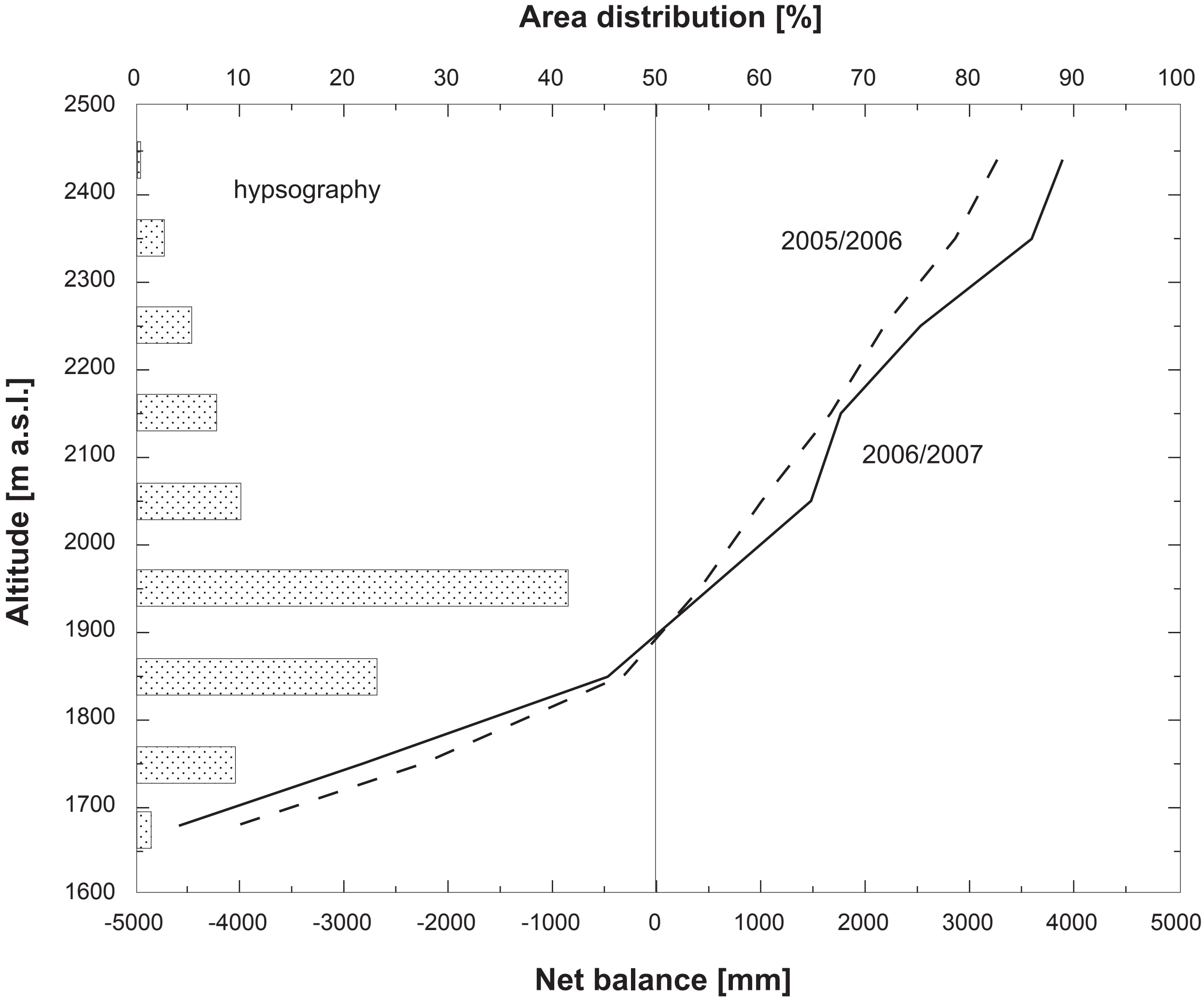
2006/2007



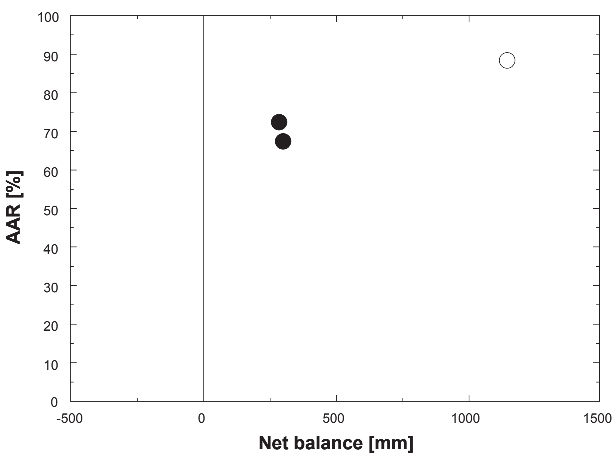


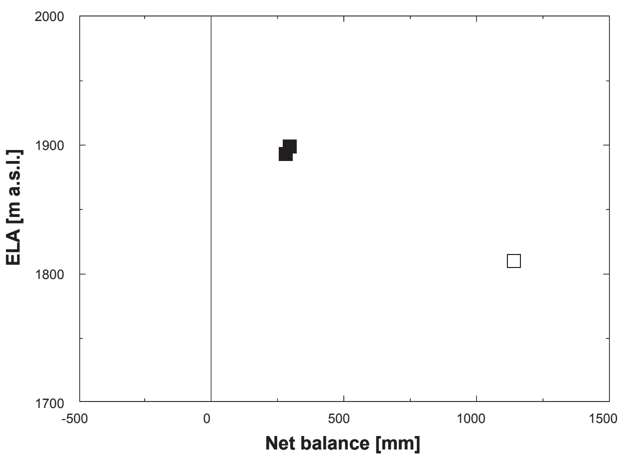
Brewster Glacier (NEW ZEALAND)

3.11.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.11.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





3.12 NIGARDSBREEN (NORWAY/WEST NORWAY)

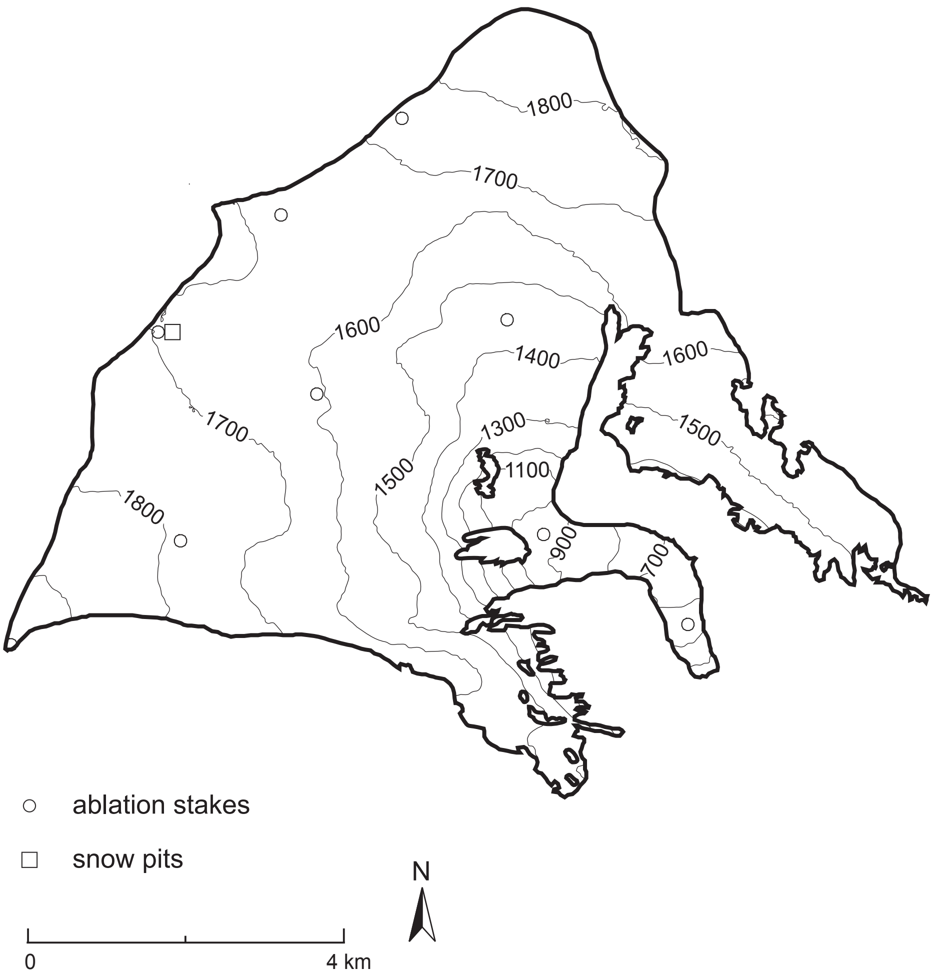
COORDINATES: 61.72 N / 07.13 E

Photo taken by B. Kjøllmoen, 31st of July 2002.

Nigardsbreen is one of the largest outlet glaciers (47.8 km^2) of the Jostedalsbreen Ice Cap in Southern Norway and reaches from 1960 m to 320 m a.s.l. Its wide accumulation area discharges into a narrow tongue, both being generally exposed to the south-east. The glacier is assumed to be entirely temperate and the periglacial area to be predominantly free of permafrost. Average annual precipitation for the 1961–1990 period is 1380 mm and mean annual air temperature at the equilibrium line is estimated at −3 °C. Since the beginning of detailed mass balance measurements in 1962, glacier thickness has greatly increased, especially after 1988.

In 2005/06, the winter balance was +1750 mm w.e. (73 % of the mean value for the total observation period) and summer balance was −3150 mm w.e. (160 % of the average 1962–2005). The resulting mass balance is −1400 mm w.e. and the calculated equilibrium line altitude is about 1850 m a.s.l. In 2006/07, the winter balance was +3090 mm w.e. (131 % of the average for the period 1962–2006) and summer balance was −2045 mm w.e. (103 % of the long-term mean). The resulting mass balance was +1045 mm w.e. The calculated equilibrium line altitude is about 1320 m a.s.l. Since 1962, the cumulative mass balance has been calculated as 18000 mm w.e.

3.12.1 Topography and observation network

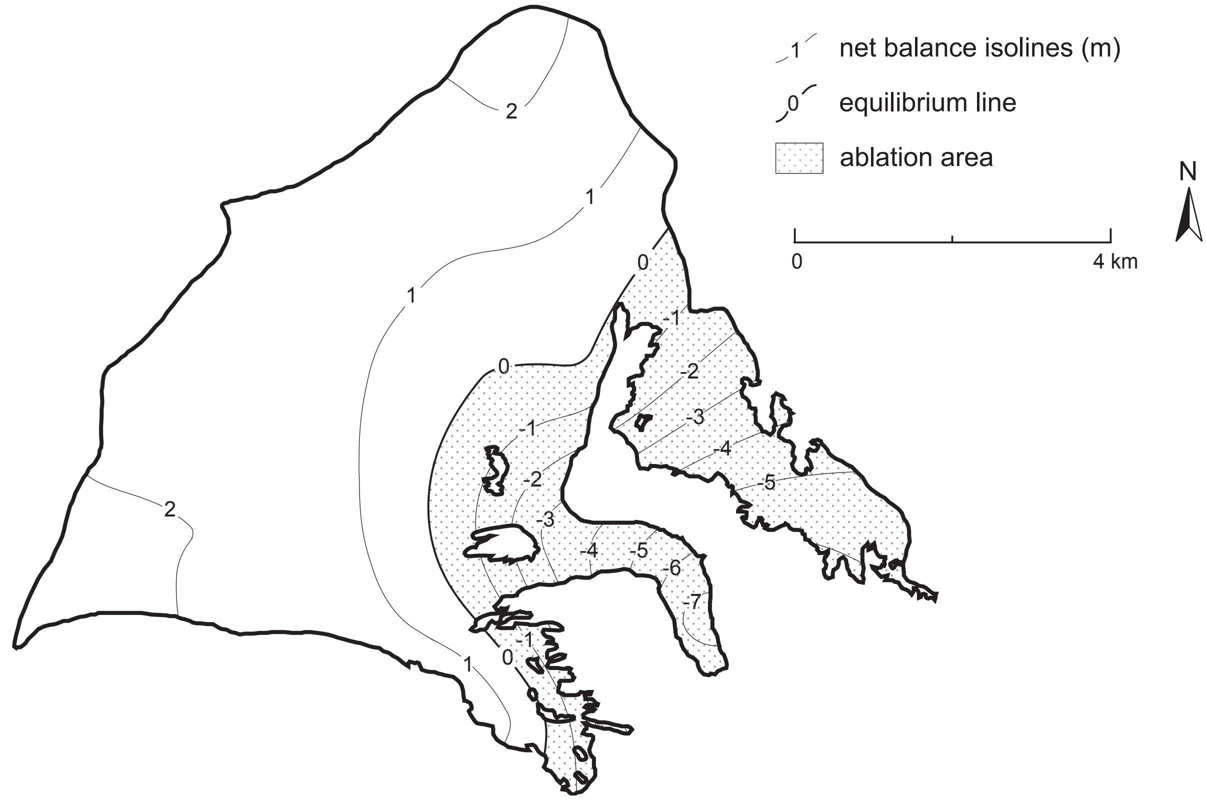


Nigardsbreen (NORWAY)

3.12.2 Net balance maps 2005/2006 and 2006/2007

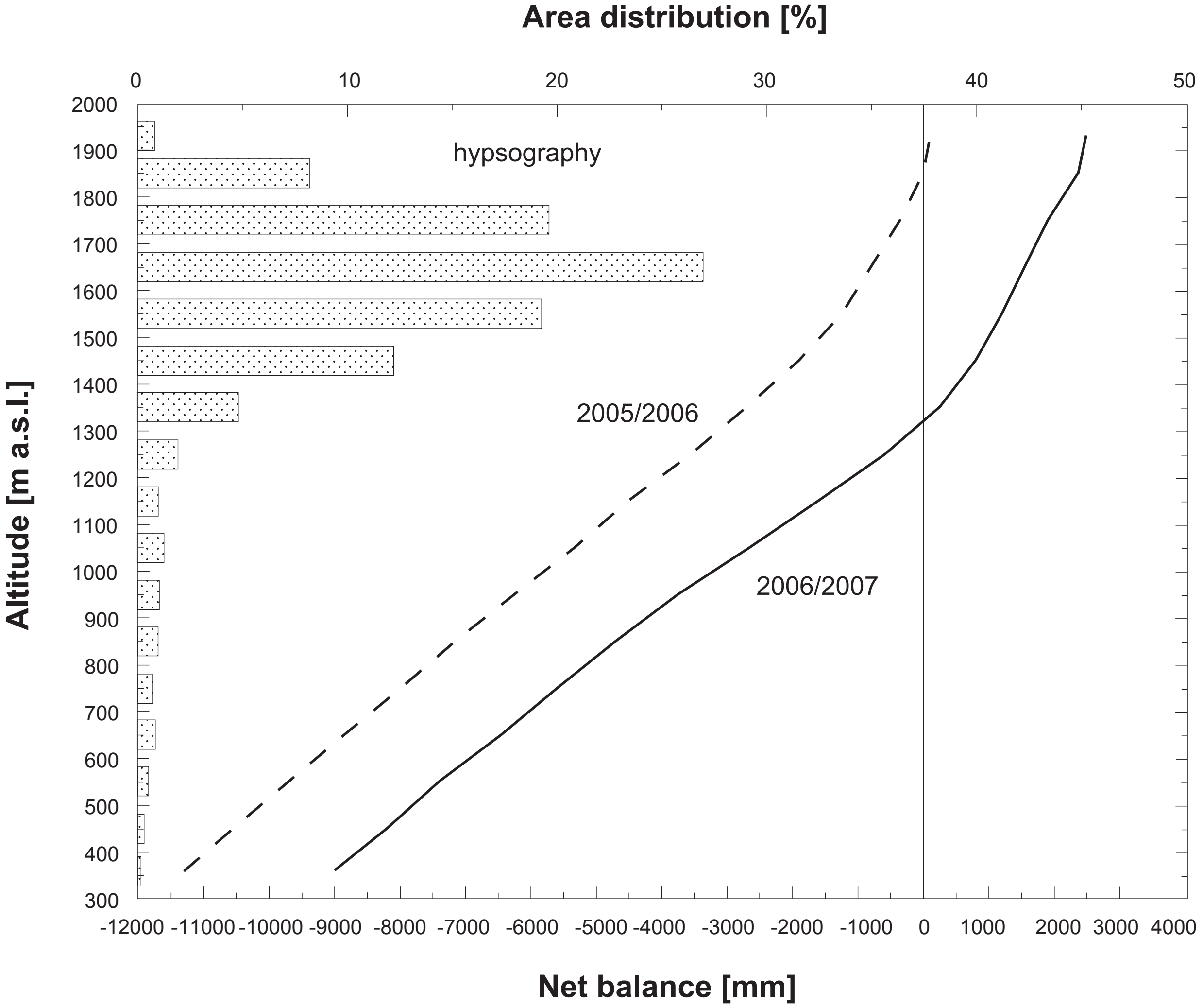
2005/2006

2006/2007

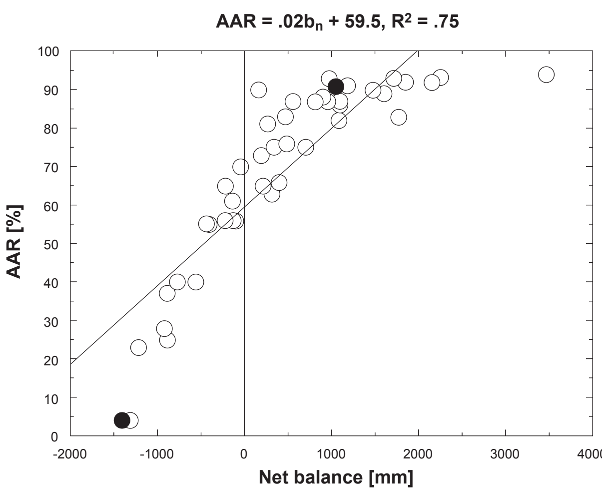


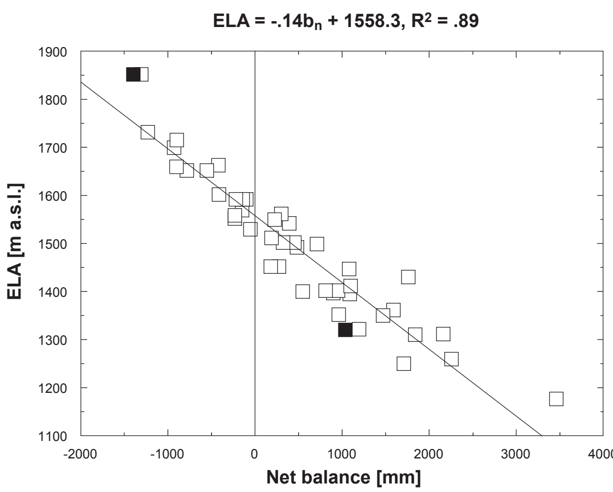
Nigardsbreen (NORWAY)

3.12.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.12.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





Nigardsbreen (NORWAY)

3.13 WALDEMARBREEN (NORWAY/SPITSBERGEN)

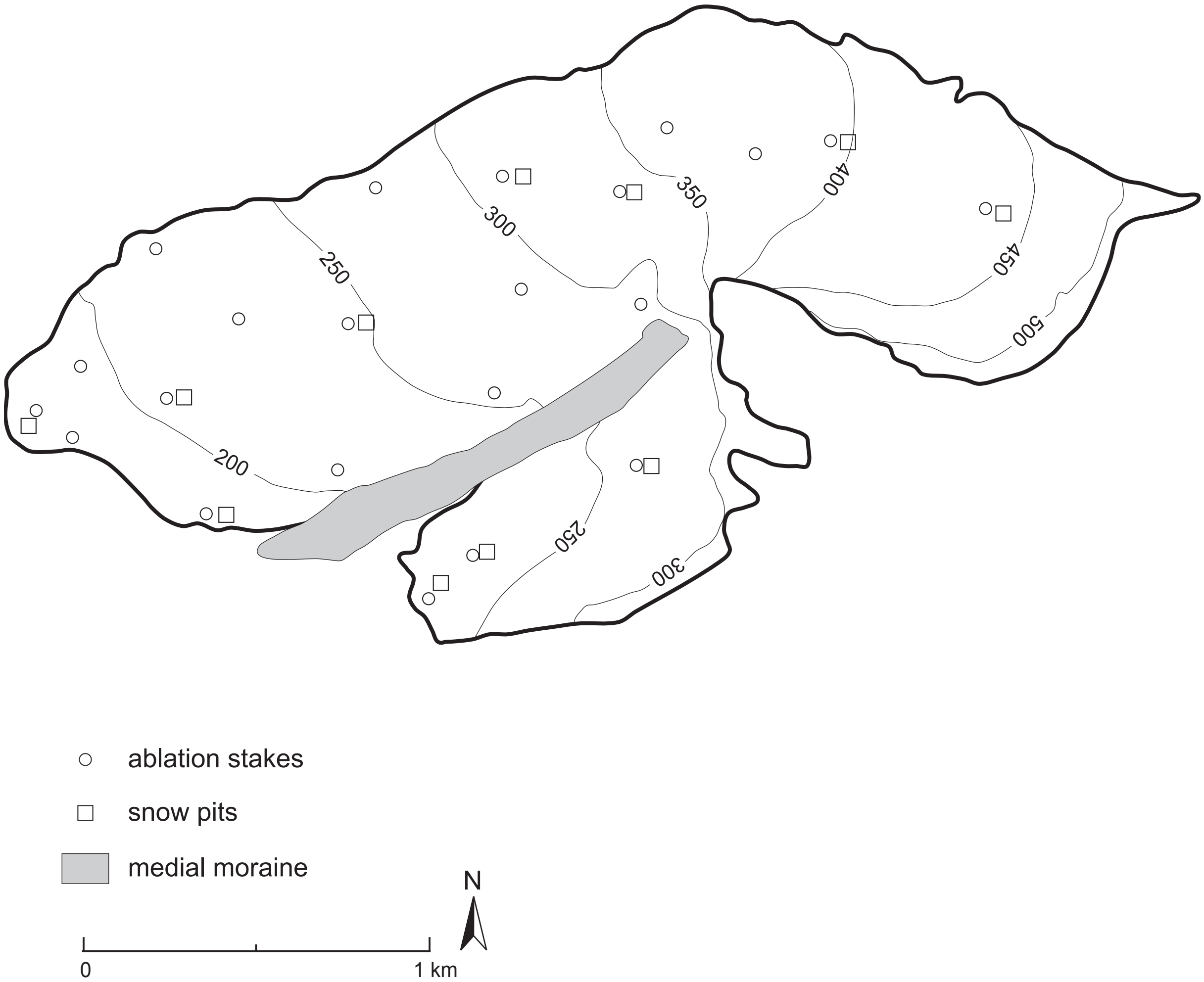
COORDINATES: 78.67 N / 12.00 E

Photo taken by I. Sobota, summer 2007.

Waldemarbreen is located in the northern part of the Oscar II Land, north-western Spitsbergen and flows downvalley to the Kaffiøyra plane. Kaffiøyra is a coastal lowland situated on the Forlandsundet. The glacier is composed of two parts separated by a 1600 m long medial moraine. It occupies an area of 2.5 km^2 and extends from 500 m to 140 m a.s.l. with a general exposure to the west. Mean annual air temperature in this area is about −4 to −5 °C and annual precipitation is generally 300–400 mm. Since the nineteenth century the surface area of the Kaffiøyra glaciers has decreased by approximately 35 %. Recently the Waldemarbreen has been retreating. Detailed mass balance investigations have been conducted since 1995.

The balance in 2005/06 showed a net mass loss of −747 mm w.e., winter accumulation +550 mm w.e. and summer ablation −1297 mm w.e. The ablation in 2006/07 was also higher than normal (−1292 mm w.e.) and the accumulation was +521 mm w.e., resulting in a balance of –771 mm w.e. The mean value of the mass balance for the period 1995–2007 is −587 mm w.e.

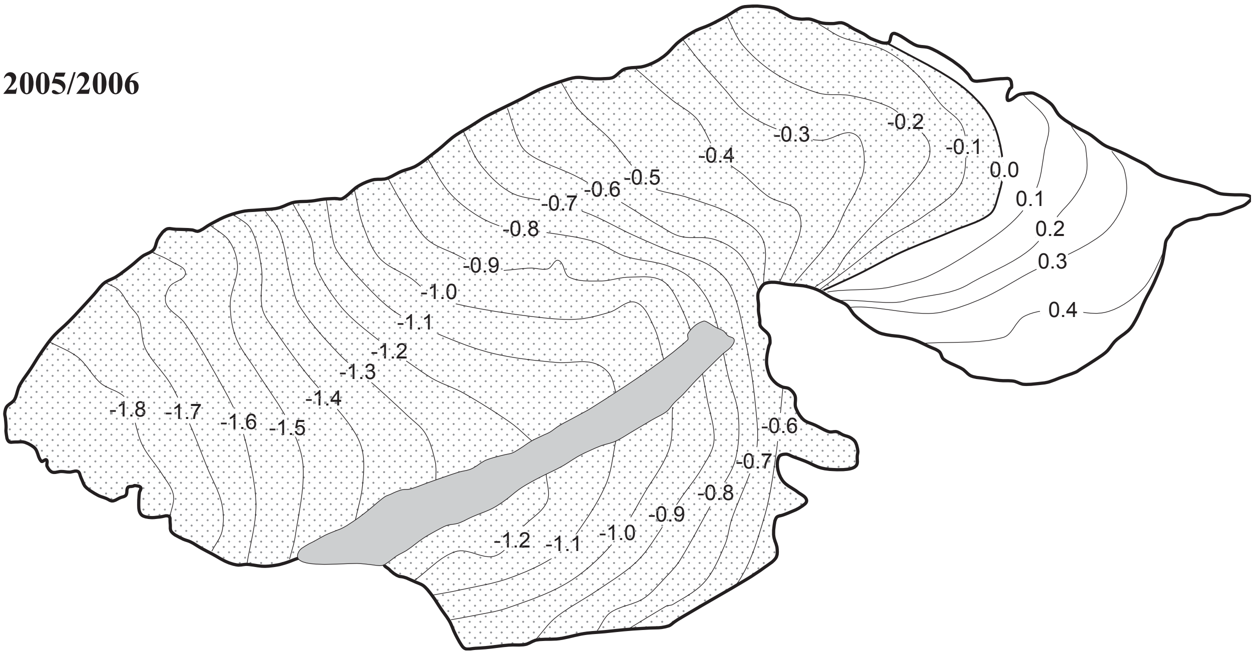
3.13.1 Topography and observation network



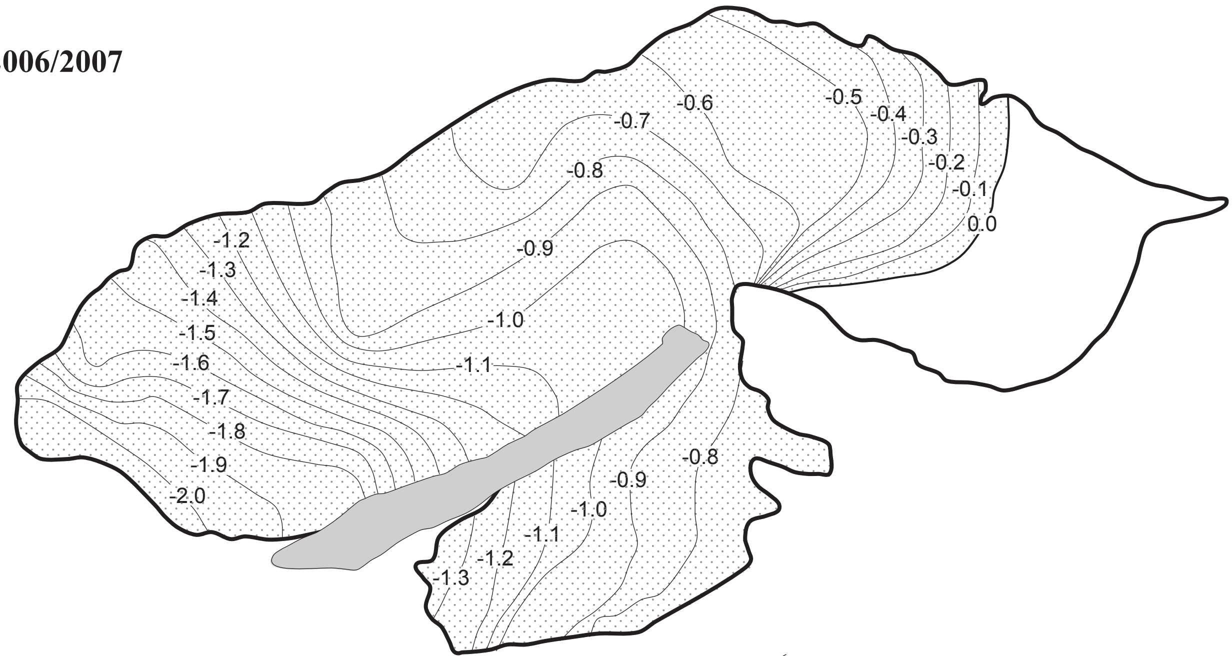
Waldemarbreen (NORWAY)

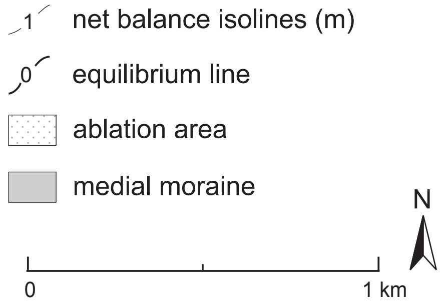
3.13.2 Net balance maps 2005/2006 and 2006/2007

2005/2006



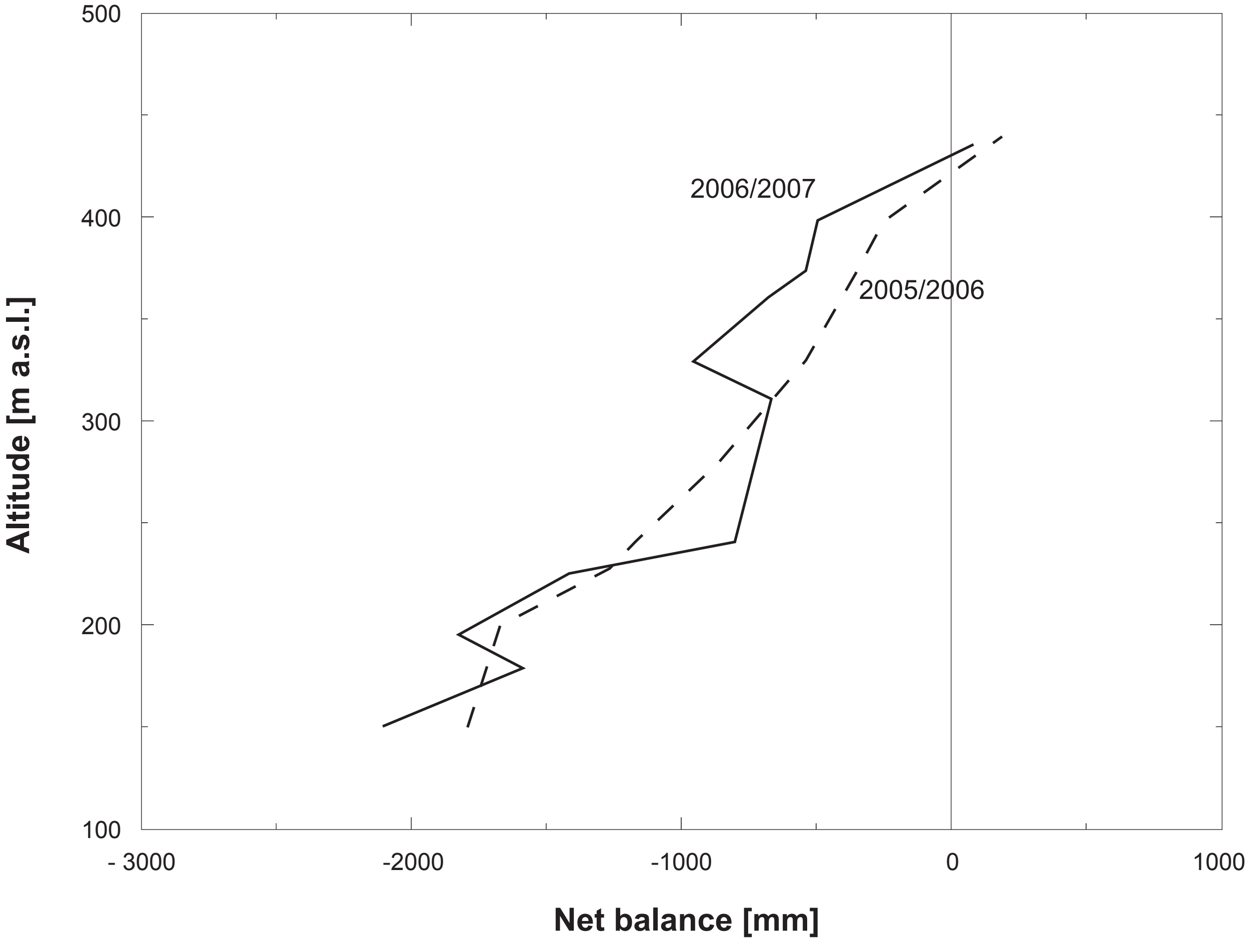
2006/2007



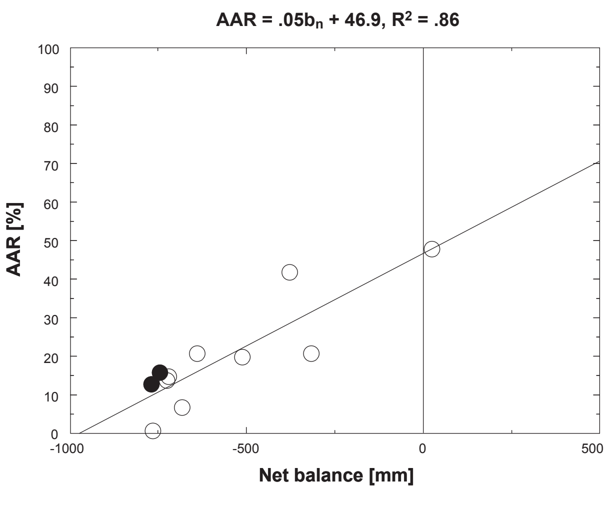


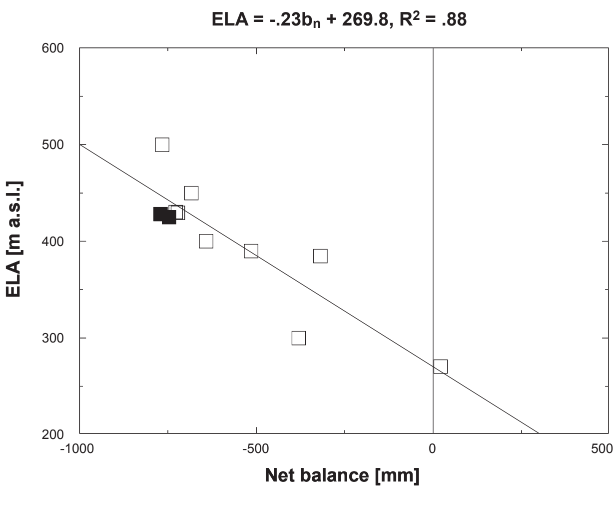
Waldemarbreen (NORWAY)

3.13.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.13.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





Waldemarbreen (NORWAY)

3.14 DJANKUAT (RUSSIA/NORTHERN CAUCASUS)

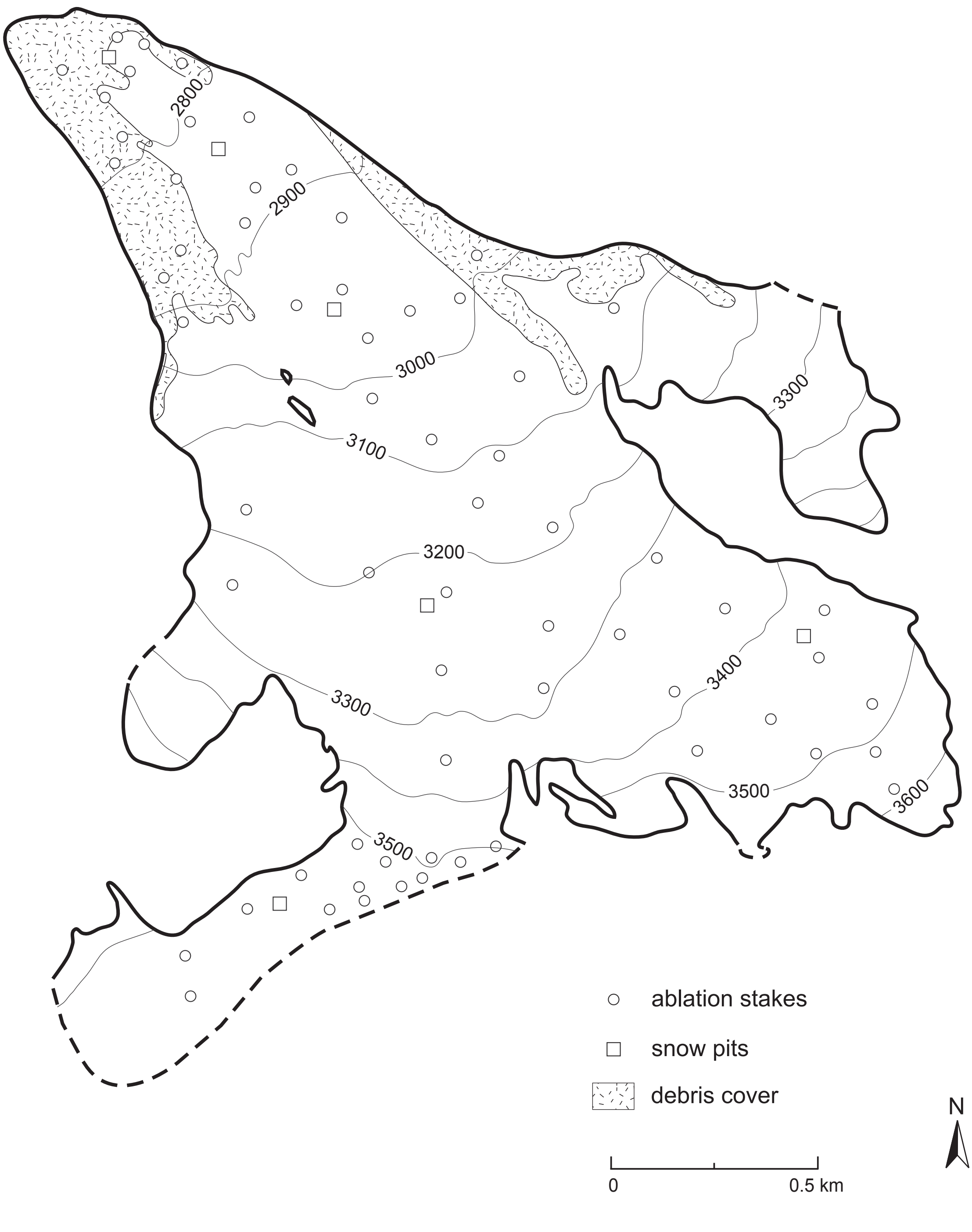
COORDINATES: 43.20 N / 42.77 E

Photo taken by V. Popovnin in August 2001.

The valley-type glacier is located on the northern slope of the central section of the Main Caucasus Ridge and extends from 3700 m to 2720 m a.s.l. Its surface area is 2.93 km^2 and the exposure is to the north-west. Mean annual air temperature at the ELA (ca. 3200 m a.s.l. for balanced conditions) is −3 to −4.5 °C and the glacier is temperate. Periglacial permafrost is highly discontinuous. Average annual precipitation as measured near the snout is 1100 to 1200 mm, but roughly three times this amount at the ELA. Seven 1:10000 topographic maps (from 1968, 1974, 1984, 1992, 1996, 1999 and 2006) exist at Moscow State University but are not yet published. The peculiarity of the glacier is the migration of the ice divide on the firn plateau of the crest zone, redistributing mass flux between adjacent slopes of the main ridge.

Two reported years were extraordinarily unfavourable for the glacier. Such huge biannual ice loss (−800 mm w.e. and −2010 mm w.e.) has never been registered throughout the 40-year monitoring period. The glacier experienced considerable deficits in winter snow (7 and 26 %), but much more decisive was the unusually high ablation: it exceeded its norm by 20 % in 2005/06 and more than 1.5 times the following year. Ablation (ca. 4000 mm w.e.) and mass balance in 2006/07 broke records, – first of all, owing to an extremely long melt season (at the expense of springtime, particularly) in the lowest altitudinal spans. The probability of the registered ablation value is estimated as once per 70 years. This resulted in a noticeable morphological transformation of the terminal zone of the snout as well as in the icefall zone in the middle course where a long outcrop of the former subglacial barrier emerged from under the ice, partly breaking the continuity of the glacier body and depriving its left debris-covered snout periphery of nourishment from the upper reaches.

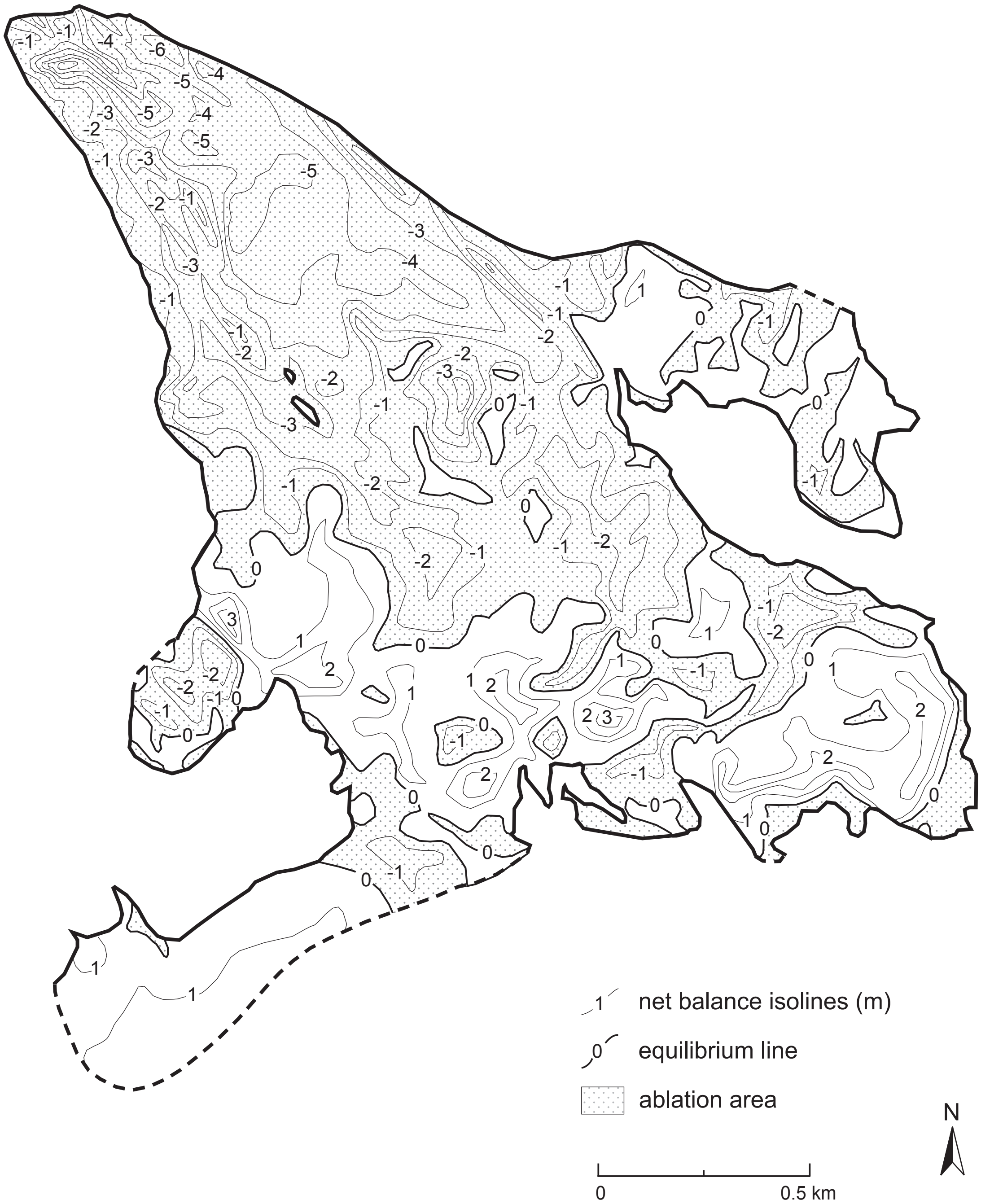
3.14.1 Topography and observation network



Djankuat (RUSSIA)

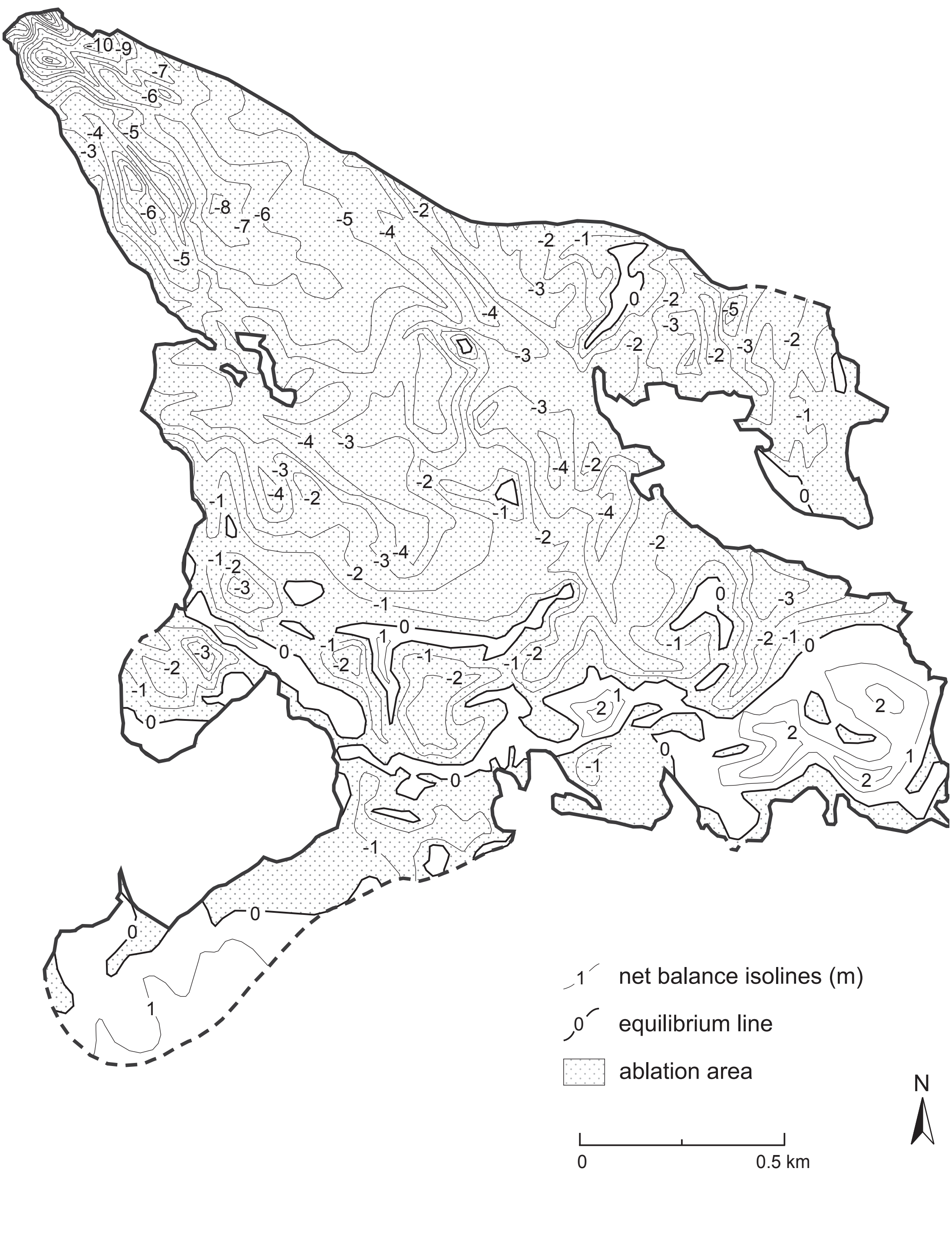
3.14.2 Net balance maps 2005/2006 and 2006/2007

2005/2006



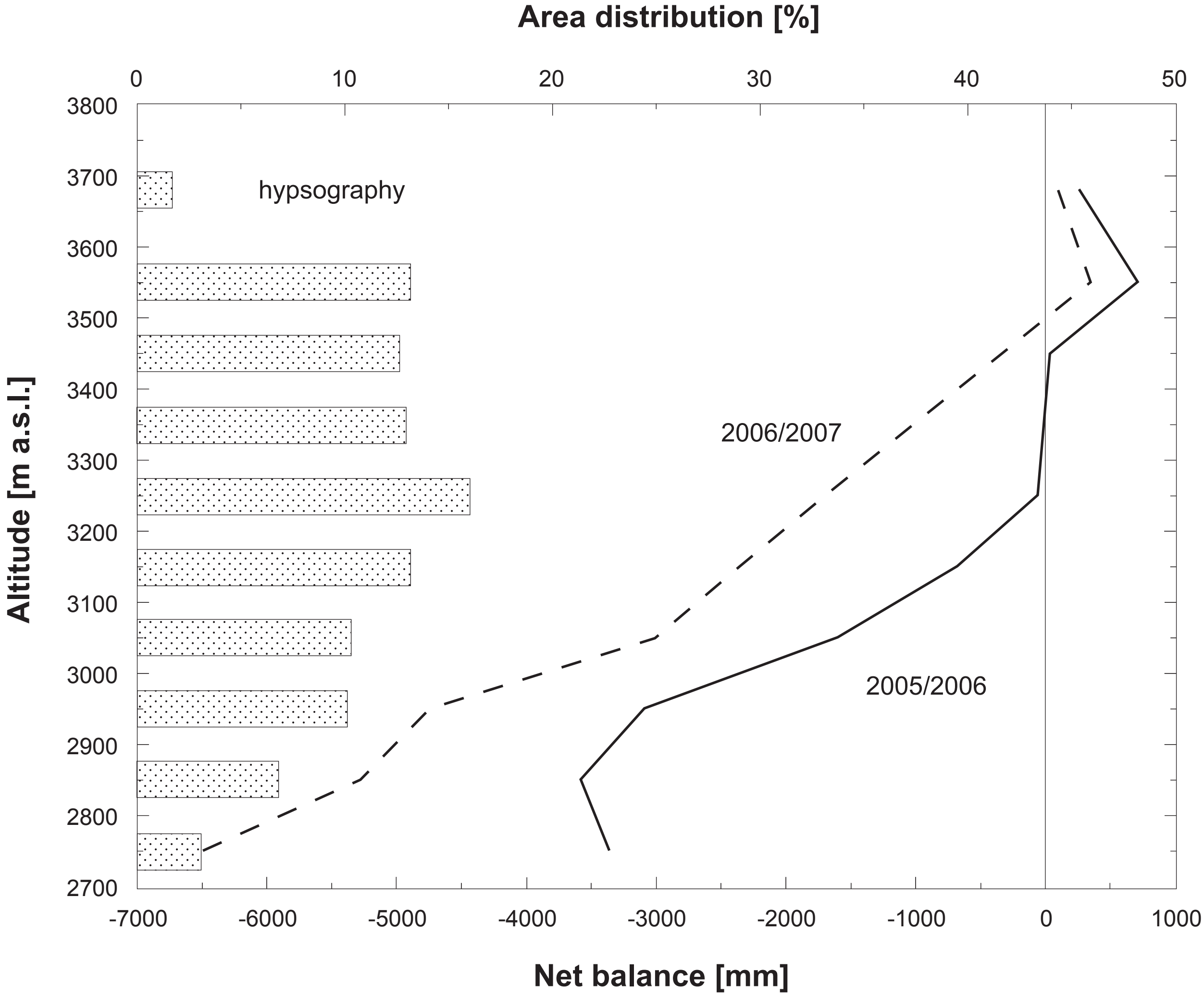
Djankuat (RUSSIA)

2006/2007

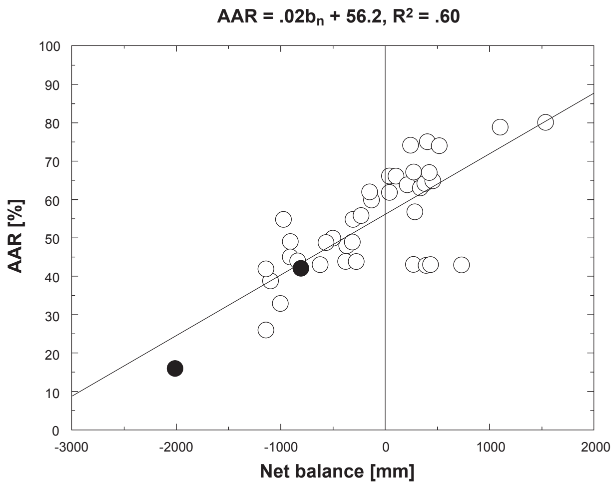


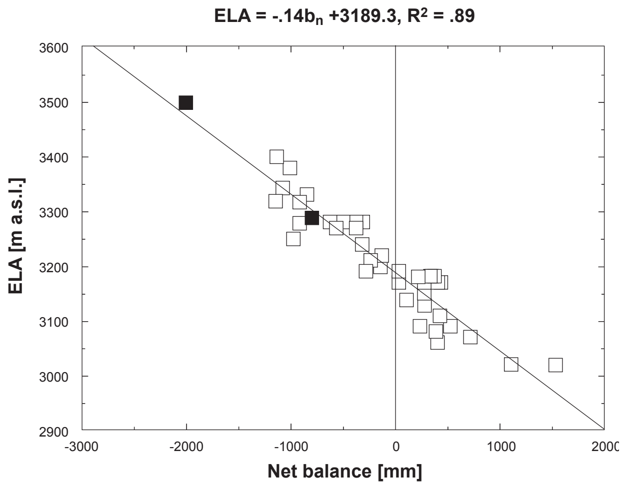
Djankuat (RUSSIA)

3.14.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.14.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





Djankuat (RUSSIA)

3.15 MALIY AKTRU (RUSSIA/ALTAY)

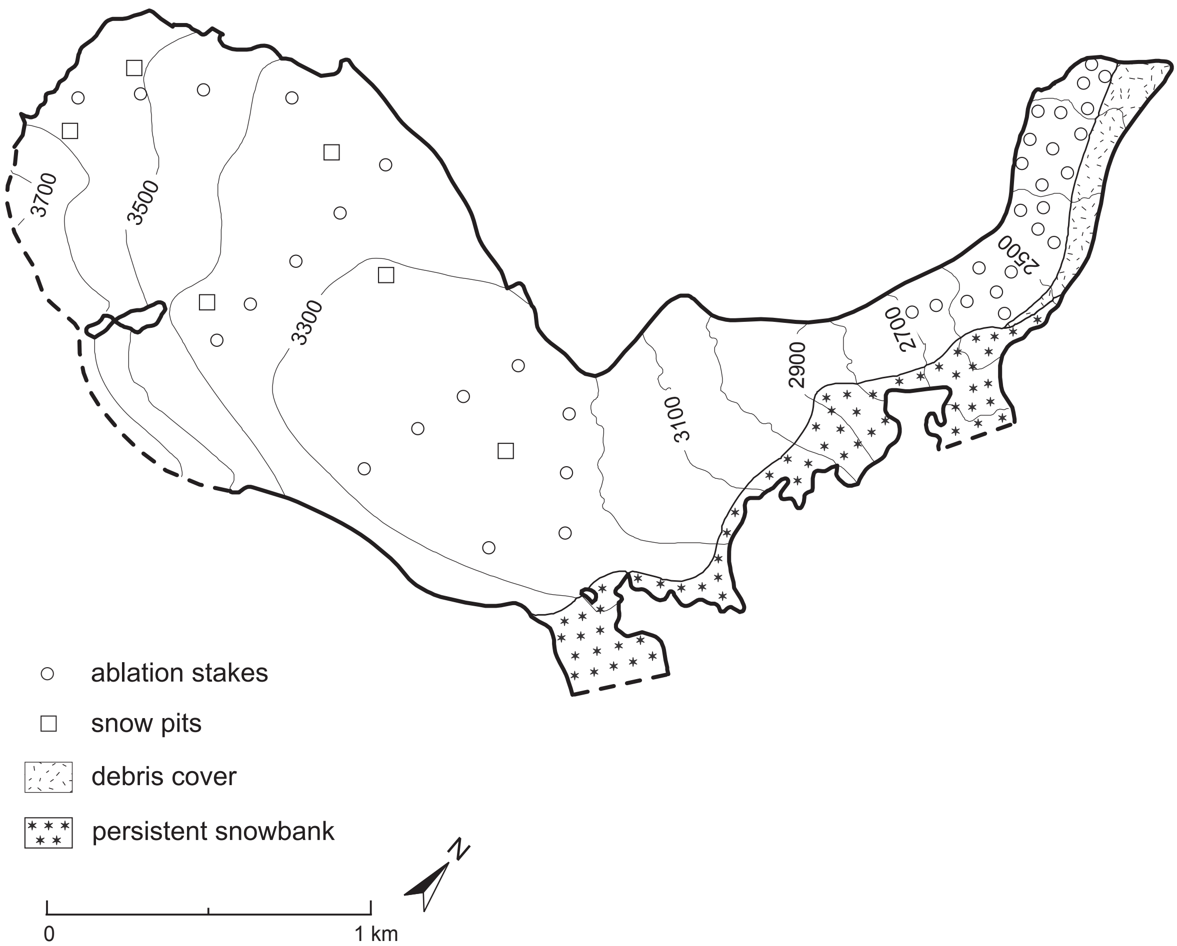
COORDINATES: 50.08 N / 87.75 E

Photo taken by Y.K. Narozhniy, 2nd of July 1992.

The valley-type glacier is located on the northern slope of the North Chuyskiy Range of the Russian Altai Mountains. It extends from 3714 m to 2246 m a.s.l., has a surface area of 2.72 km^2 and is exposed to the east and north. It has an average thickness of 90 m (max. 234 m) and its total volume is estimated to be 0.25 km^3. Mean annual air temperature at the equilibrium line of the glacier (around 3160 m a.s.l. for balanced conditions) is −9 to −10 °C. The glacier is polythermal and surrounded by continuous to discontinuous permafrost. Average annual precipitation, as measured at 2130 m a.s.l., is about 540 mm. Mass balances of three glaciers within the same basin are being determined.

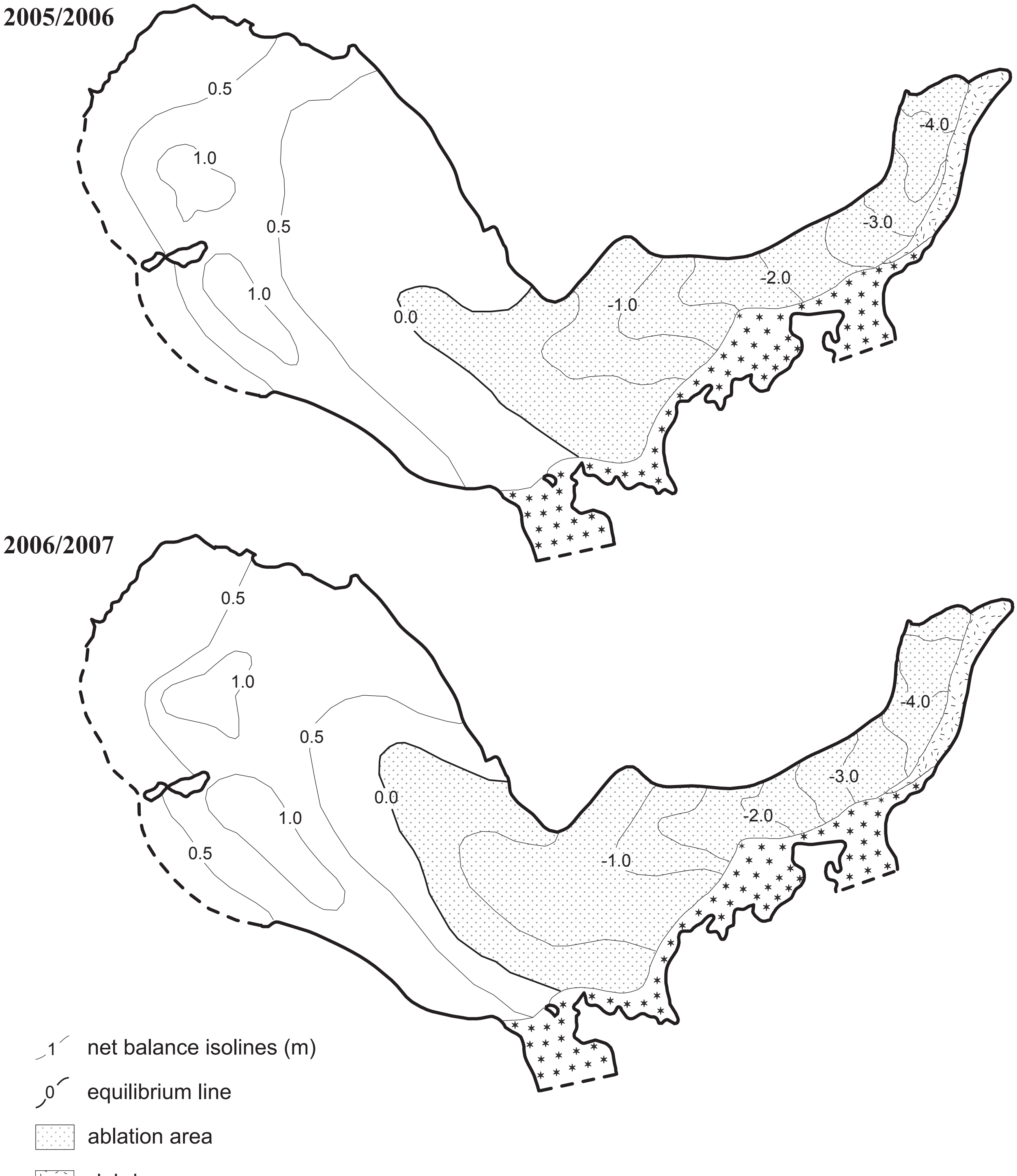
In both reported years, 2005/06 and 2006/07, total accumulation was rather close to its norm (the correspondent deviations were −5 and −8 %), and annual ablation exceeded its long-term mean value by 10 and 14 %, respectively. As a result, mass balance remained negative as in the previous years. However, both the budget parameters and frontal retreat values were influenced considerably by the consequences of earthquakes in 2003–2004. For instance, mass loss due only to ice collapses from the terminal part of Maliy Aktru snout was about 40–60 mm w.e. (averaged over the entire glacier surface), and the terminus retreated at a velocity of 18–25 m a^{-1}, that is, 3–5 times higher than the common rate.

3.15.1 Topography and observation network



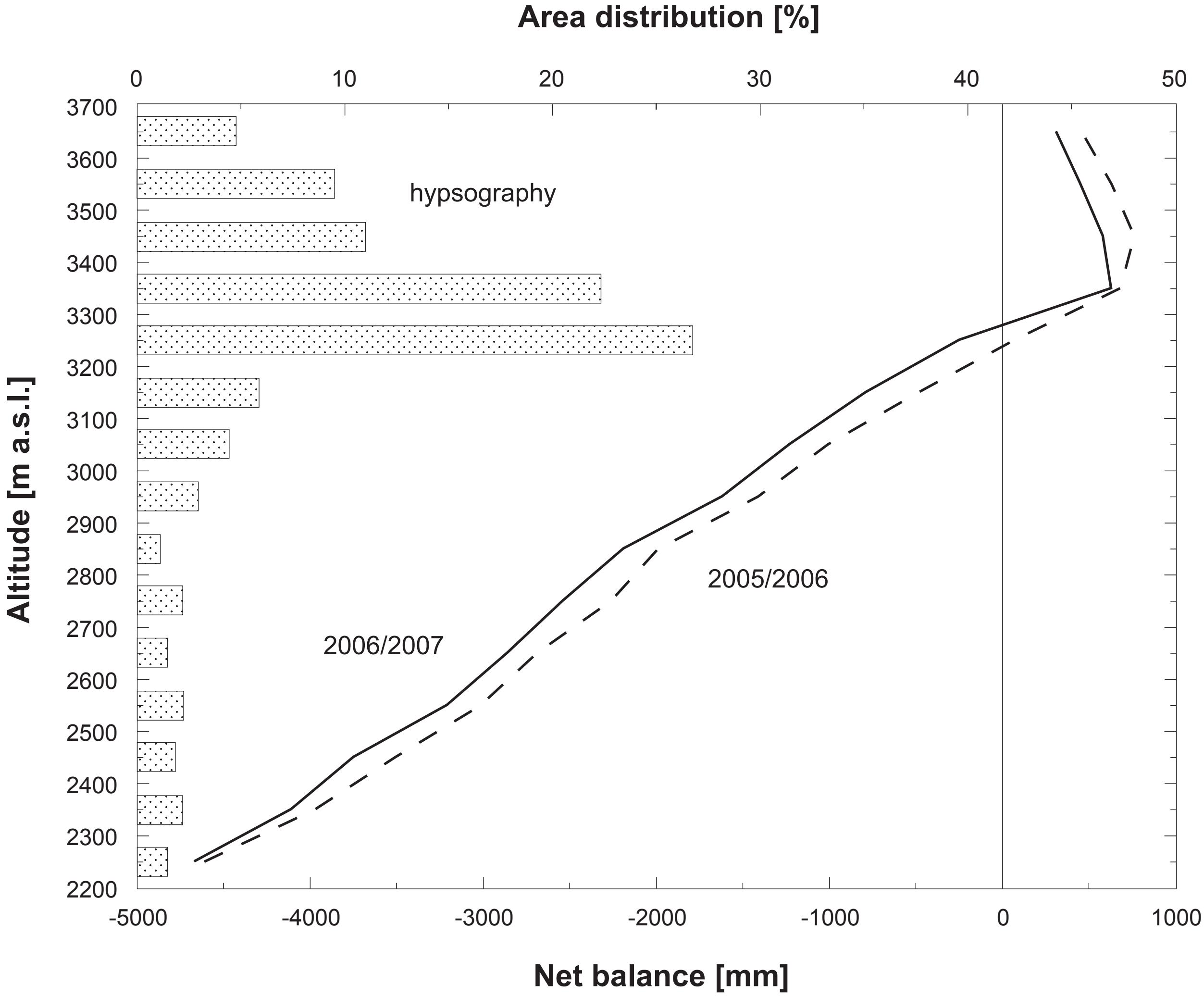
Maliy Aktru (RUSSIA)

3.15.2 Net balance maps 2005/2006 and 2006/2007

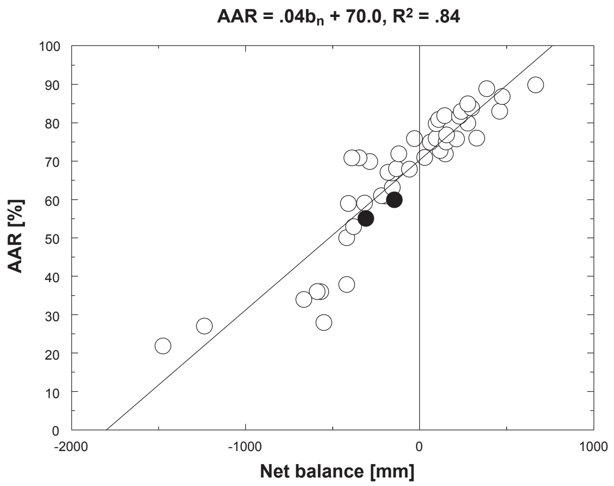


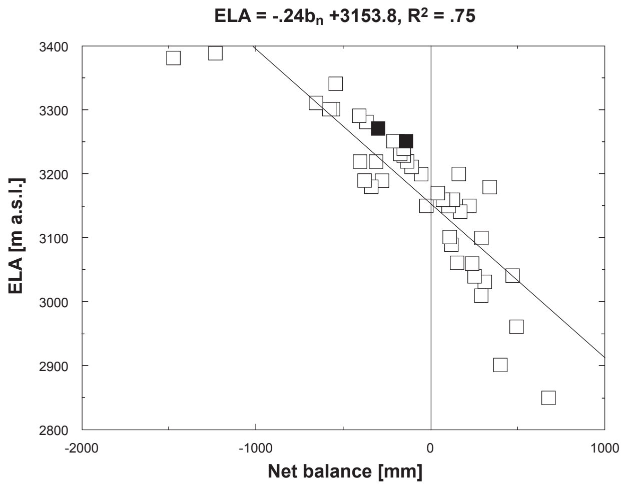
Maliy Aktru (RUSSIA)

3.15.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.15.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





Maliy Aktru (RUSSIA)

3.16 STORGLACIÄREN (SWEDEN/NORTHERN SWEDEN)

COORDINATES: 67.90 N / 18.57 E

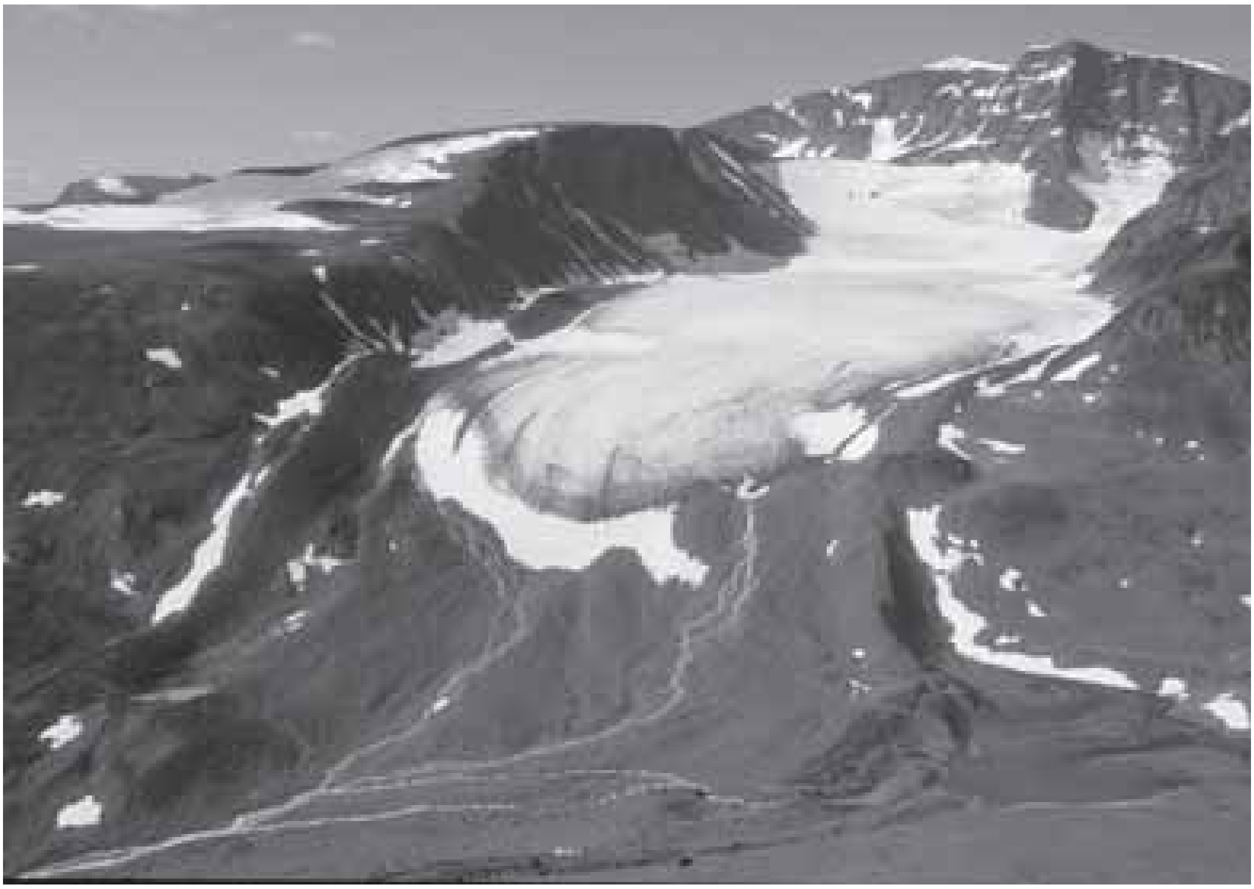
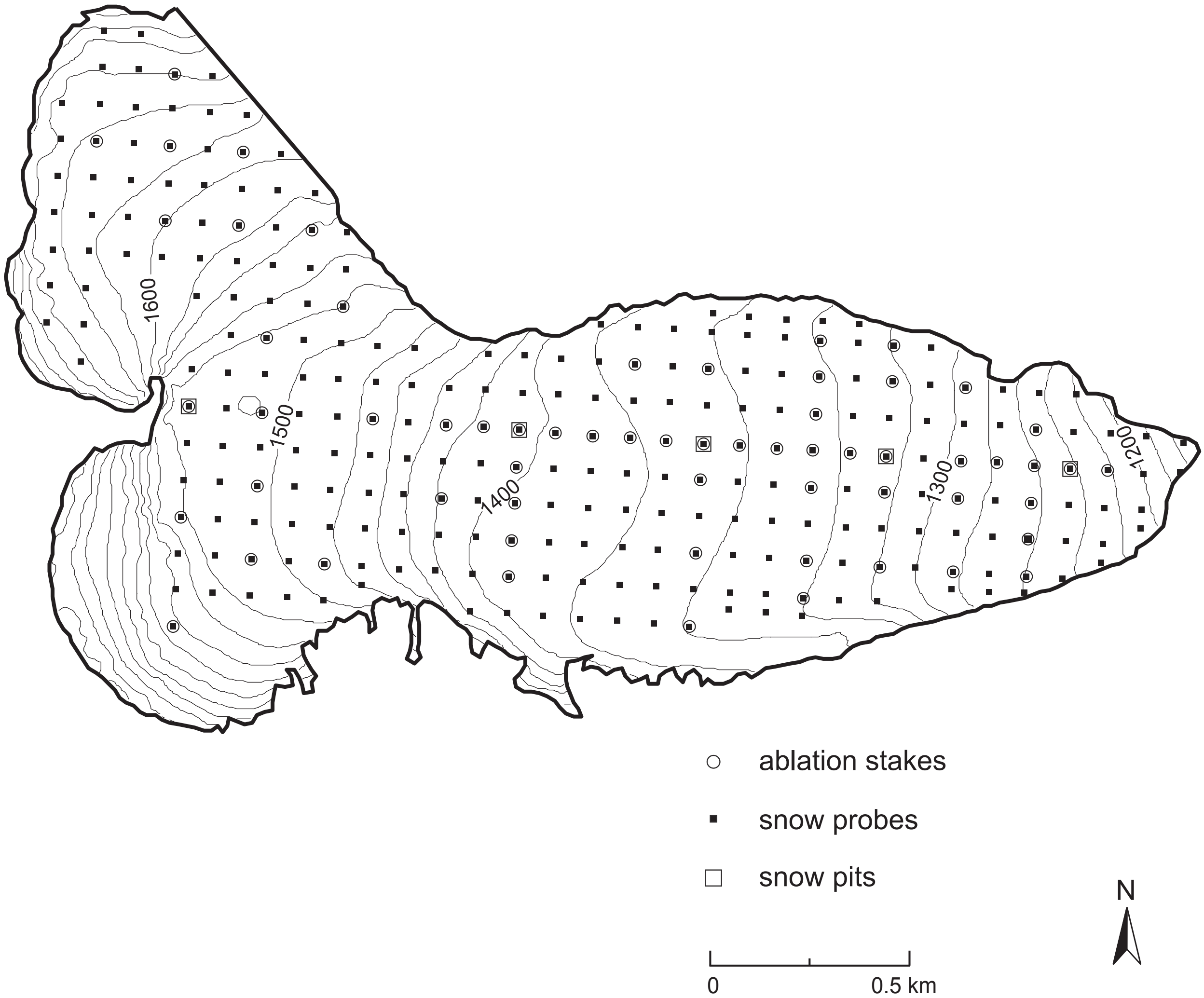


Photo taken by P. Holmlund on 4th of August 2004.

Storglaciären in the Kebnekaise Mountains of northern Sweden is a small valley-type glacier with a divided accumulation area and a smooth longitudinal profile. It is exposed to the east, maximum and minimum elevations are 1750 m and 1130 m a.s.l., surface area is 3.12 km^2, and average thickness is 95 m (maximum thickness is 250 m). Mean annual air temperature at the equilibrium line of the glacier (around 1450 m a.s.l. for balanced conditions) is about −6 °C. Approximately 85 % of the glacier is temperate with a cold surface layer in its lower part (ablation area), and its tongue lying in discontinuous permafrost. Average annual precipitation is about 1000 mm at the nearby Tarfala Research Station.

The net balance in 2005/06 was negative (−1720 mm w.e.) with an ELA at 1615 m a.s.l and a small AAR of 17 %. In 2006/07, the net balance was positive (+410 mm w.e.), which was also reflected in the ELA at 1480 m a.s.l. and the AAR of 50 %. Aerial photographs and corresponding glaciological maps are available for the years 1949/59/69/80/90/99. Recently, diapositives of the original photographs were reprocessed using uniform photogrammetric methods. A comparison of the glaciological mass balance with these new volume changes is in progress.

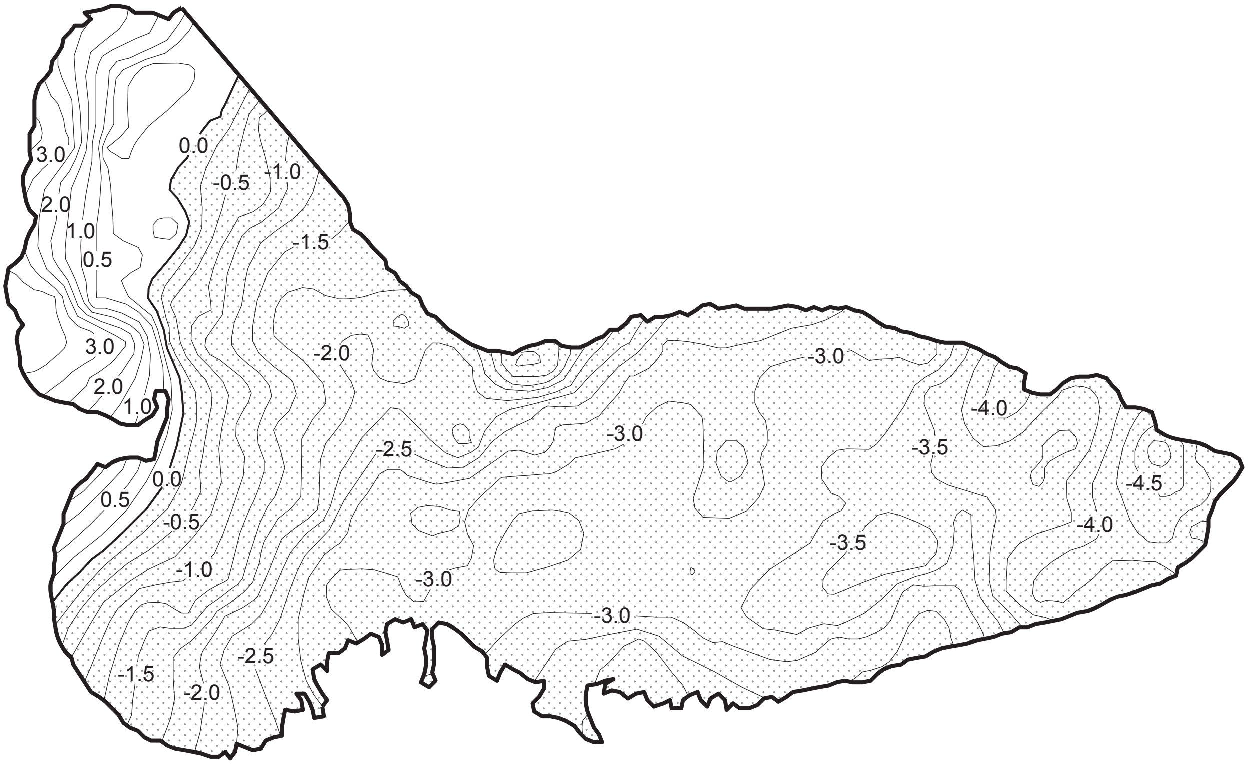
3.16.1 Topography and observation network



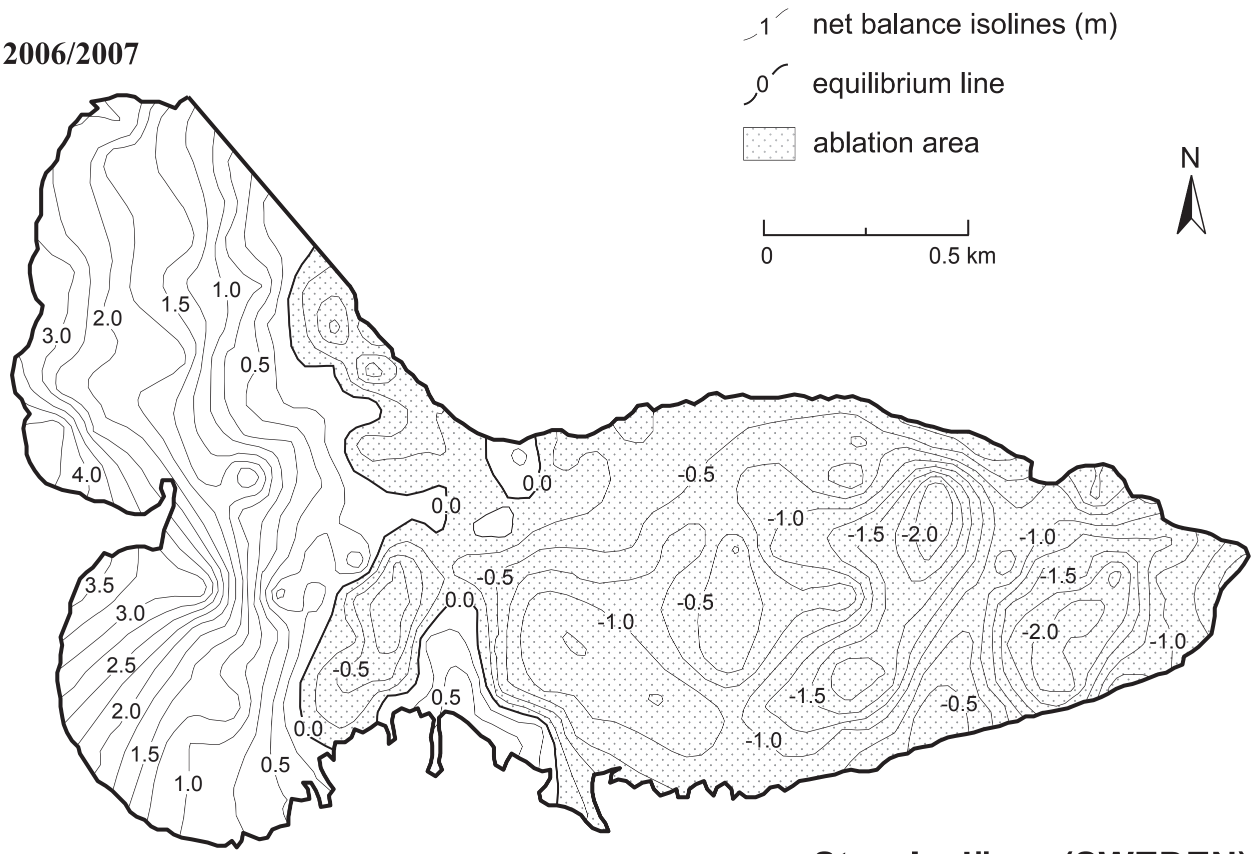
Storglaciären (SWEDEN)

3.16.2 Net balance maps 2005/2006 and 2006/2007

2005/2006

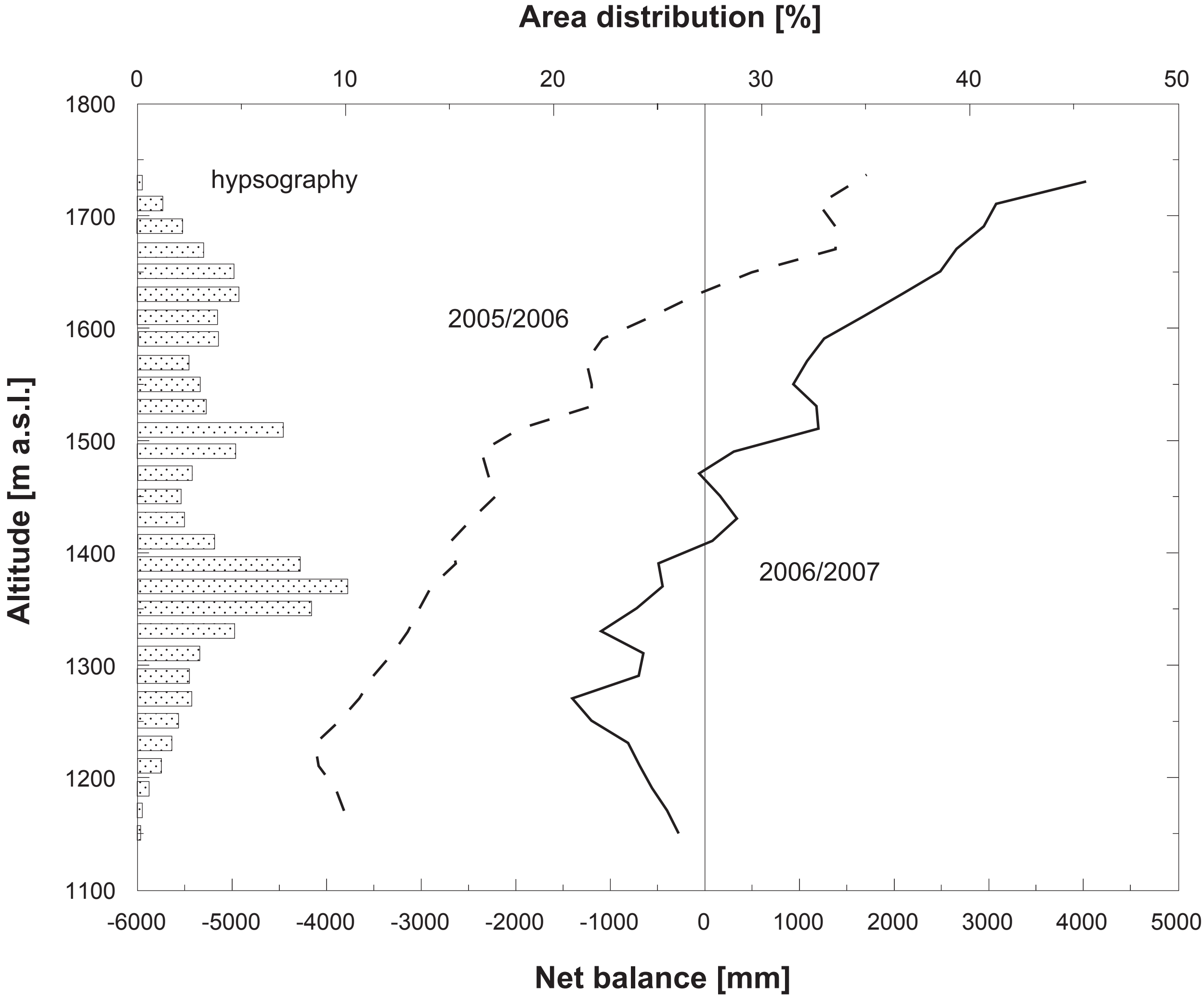


2006/2007

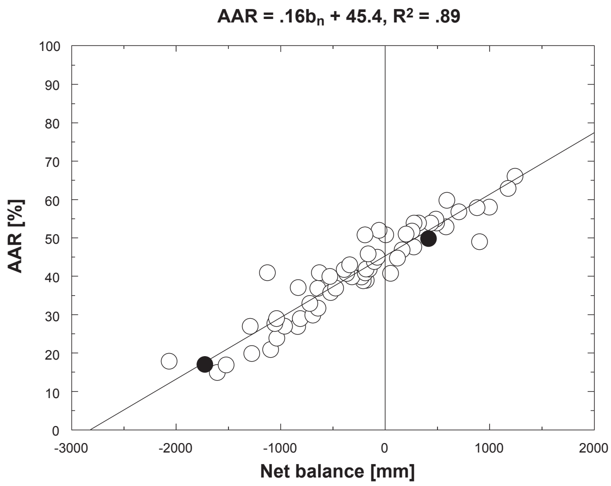


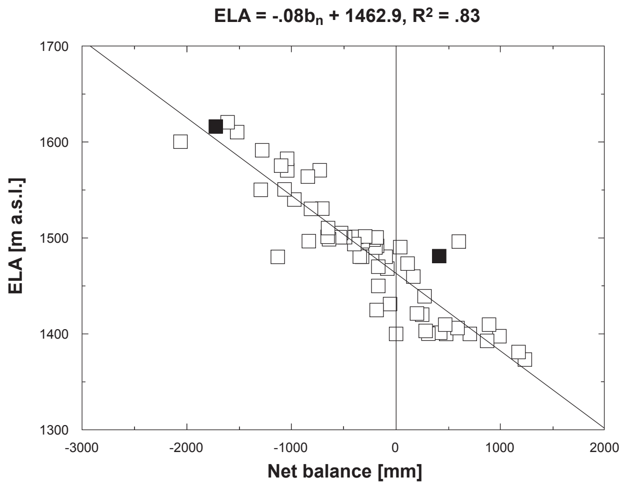
Storglaciären (SWEDEN)

3.16.3 Net balance versus altitude (2005/2006 and 2006/2007)



3.16.4 Accumulation area ratio (AAR) and equilibrium line altitude (ELA) versus specific net balance for the whole observation period





Storglaciären (SWEDEN)

4 FINAL REMARKS AND ACKNOWLEDGEMENTS

Continuous mass balance records for the period 1980–2007 are now available for 30 glaciers from 9 mountain ranges. These glaciers have well-documented, long-term mass balance measurements based on the direct glaciological method (cf. Østrem and Brugman, 1991) and are not dominated by non-climatic drivers such as calving or surge dynamics. Corresponding results from this sample of glaciers in North and South America and Eurasia are summarized in Table 4.1 (all mm values in water equivalent):

Table 4.1: Summarized mass balance data. The mean specific (annual) net balance of 30 glaciers averaged for the years 2000–2007, compared to the mean of the annual means of the last 20 years, is shown in the upper table. A statistical overview of the 30 glaciers during the two reported years is given in the lower table.

		1980–1999			2000–2007	
mean specific (annual) net balance	−	296 mm		−	706 mm	
standard deviation of means	±	257 mm		±	410 mm	
minimum mean value	−	728 mm	(1998)	−	1269 mm	(2003)
maximum mean value	+	107 mm	(1983)	−	61 mm	(2000)
range		835 mm			1208 mm	
positive mean balances		15 %			0 %	
positive balances		32 %			18 %	

		2005/2006			2006/2007	
mean specific (annual) net balance	−	1247 mm		−	676 mm	
standard deviation	±	835 mm		±	1058 mm	
minimum value	−	3190 mm	Ålfotbreen	−	2745 mm	Caresèr
maximum value	+	560 mm	Echaurren Norte	+	1270 mm	Ålfotbreen
range		3750 mm			4015 mm	
positive balances		3 %			17 %	

Taking the two reported years together, the mean mass balance was –962 mm w.e. per year. This represents more than a meter ice thickness loss per year and exceeds by about 35 % the mean mass balance since the turn of the century (2000–2007: –706 mm w.e.), and is more than three times the average of 1980–1999 (–296 mm w.e.). During this most recent time interval, the maximum loss of the 1980–1999 time period (–728 mm w.e. in 1998) was already exceeded for the third time (–1269 mm w.e. in 2003, –744 mm w.e. in 2004, –1247 mm in 2006); the percentage of positive glacier mass balances decreased from an average of 32 % in the 1980s to 18 % and there were no more years with an overall positive mass balance (15 % during 1980–1999). The melt rate and loss in glacier thickness continues to be extraordinary. This development further confirms the accelerating trend in worldwide glacier disappearance, which has become more and more obvious during the past two decades.

The mean of the 30 glaciers included in the analysis is influenced by the large proportion of Alpine and Scandinavian glaciers. A mean value is therefore also calculated using only one single value (averaged) for each of the 9 mountain ranges concerned (Table 4.2). Furthermore, a mean was calculated for all mass balances available, independently of record length. In their general trend and magnitude, all three averages rather closely relate to each other and are in good agreement with the results from a moving-sample-averaging of all available data (cf. Kaser et al., 2006; Zemp et al., 2009).

The evolution with time can be described by means of Figure 4.1:

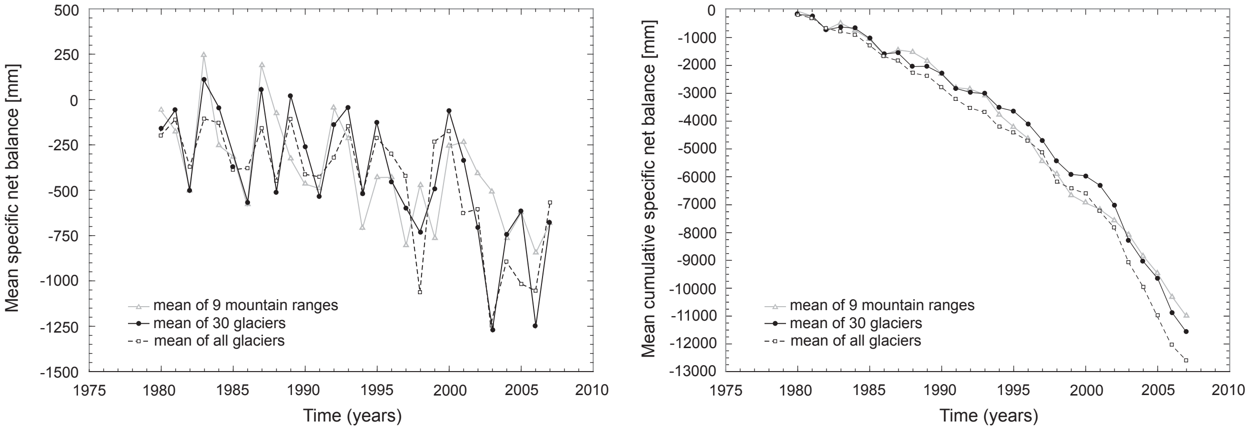


Figure 4.1: Mean specific net balance (left) and mean cumulative specific net balance (right) since 1980.

With their dynamic response to changes in climatic conditions – growth/reduction in area mainly through the advance/retreat of glacier tongues – glaciers readjust to equilibrium conditions of ice geometry with a zero mass balance. Recorded mass balances document the degree of imbalance between glaciers and climate due to the delay in dynamic response caused by the characteristics of ice flow (deformation and sliding); over longer time intervals they depend on the rate of climatic forcing. With constant climatic conditions (no forcing), balances would tend towards and become finally zero. Long-term non-zero balances are, therefore, an expression of ongoing climate change and sustained forcing. Trends towards increasing non-zero balances are caused by accelerated forcing. In the same way, comparison between present-day and past values of mass balance must take the changes of glacier area into account, which have occurred in the meantime (Elseberg et al., 2001; Nemec et al., 2009). Many of the relatively small glaciers, measured within the framework of the present mass balance observation network, have lost large percentages of their area during the past decades. The recent increase in the rates of ice loss over diminishing glacier surface areas, as compared with earlier losses related to larger surface areas, becomes even more pronounced and leaves no doubt about the accelerating change in climatic conditions, even if a part of the observed acceleration trend is likely to be caused by positive feedback processes.

Further analysis requires detailed consideration of aspects such as glacier sensitivity and the mentioned feedback mechanisms. The balance values and curves of cumulative mass balances reported for the individual glaciers (Chapter 2) not only reflect regional climatic variability but also mark differences in the sensitivity of the observed glaciers. This sensitivity has a (local) topographic component: the hypsographic distribution of glacier area with altitude (for the first time reported in selected cases with the present bulletin) and a (regional) climatic component: the change in mass balance with altitude or the mass balance gradient. The latter component tends to increase with increasing humidity and leads to stronger reactions by maritime rather than by continental glaciers. For the same reason, the mean balance values calculated above are predominantly influenced by maritime glaciers rather than by continental ones. Maritme glacier are those found in the coastal mountains of Norway or USA/Alaska, where effects from changes in precipitation may predominate over the influence of atmospheric warming. The modern tool of differencing repeat digital elevation models (DEM) provides excellent possibilities to assess how representative long time series of local mass balance measurements are with respect to large glacier samples (Paul and Haeberli, 2008) and to analyze spatial patterns of glacier thickness/volume changes in entire mountain ranges: DEM differencing, for instance, revealed that average thickness losses in southern Alaska (Larsen et al., 2007) are far higher than the averages reported here from in situ observations on various continents.

Rising snowlines and cumulative mass losses lead to changes in the average albedo and to a continued surface lowering. Such effects cause pronounced positive feedbacks with respect to radiative and sensible heat fluxes.

Table 4.2: Mass balance data for 9 mountain regions 1980–2007

Year	Cascade Mnts.	Alaska	Andes	Svalbard	Scandinavia	Alps	Altai	Caucasus	Tien Shan	Mean
1980	−972	1400	300	−475	−1055	403	−10	380	−483	−57
1981	−967	775	360	−505	194	−11	−213	−910	−271	−172
1982	−337	−245	−2420	−10	−185	−914	−460	420	−338	−499
1983	−606	15	3700	−220	756	−456	197	−970	−220	244
1984	−109	−395	−1240	−705	194	115	307	210	−667	−254
1985	−1541	515	340	−515	−451	−415	200	−380	−581	−314
1986	−1011	−60	−1570	−265	−249	−1031	73	−500	−595	−579
1987	−1703	535	950	230	925	−711	183	1540	−258	188
1988	−1305	395	2300	−505	−1215	−588	333	520	−626	−77
1989	−875	−1440	−1260	−345	1911	−906	117	40	−177	−326
1990	−834	−1555	−1300	−585	1196	−1105	107	340	−454	−466
1991	−595	−260	−860	115	80	−1200	−480	−310	−903	−490
1992	−1400	−210	1740	−120	1161	−1223	−127	−130	−109	−46
1993	−1755	−1170	−290	−955	1174	−556	227	1100	287	−215
1994	−1515	−660	−1860	−140	171	−886	−240	−840	−411	−709
1995	−1588	−765	−950	−785	589	−70	60	40	−408	−431
1996	−61	−950	−1180	−75	−643	−454	−140	−150	−207	−429
1997	−129	−2120	−2530	−570	−470	−400	−123	270	−1160	−804
1998	−2155	−135	2890	−725	221	−1664	−1110	−1000	−575	−473
1999	820	−1095	−4260	−350	−123	−699	−113	−560	−511	−766
2000	255	−490	−760	−25	988	−686	−230	−1140	−222	−257
2001	−1165	−120	1810	−405	−787	53	−190	−620	−698	−236
2002	214	−875	80	−550	−1141	−870	−357	430	−568	−404
2003	−1548	−180	2060	−845	−1392	−2557	−363	280	−13	−506
2004	−1930	−2285	−570	−1045	−161	−1039	−210	730	−347	−762
2005	−1873	−1020	−850	−870	309	−1368	87	390	−414	−623
2006	−1675	−545	560	−605	−2025	−1444	−197	−800	−872	−845
2007	−180	−1045	−130	−355	395	−1742	−297	−2010	−779	−683
Mean	−948	−499	−176	−436	13	−801	−106	−130	−449	−392

Cascade Mtns.	Place, South Cascade
Svalbard	Austre Brøggerbreen, Midtre Lovénbreen
Andes	Echaurren Norte
Alaska	Gulkana, Wolverine
Scandinavia	Engabreen, Ålfotbreen, Nigardsbreen, Gråsubreen, Storbreen, Hellstugubreen, Hardangerjøkulen, Storglaciären
Alps	Saint Sorlin, Sarennes, Silvretta, Gries, Sonnblickkees, Vernagtferner, Kesselwandferner, Hintereisferner, Caresèr
Altai	No. 125 (Vodopadniy), Maliy Aktru, Leviy Aktru
Caucasus	Djankuat
Tien Shan	Ts. Tuyuksuyskiy, Urumqihe S. No. 1

Albedo changes are especially effective in enhancing melt rates and can also be caused by input of dust (Oerlemans et al., 2009). The cumulative length change of glaciers is the result of all effects combined, and constitutes the key to a global intercomparison of decadal to secular mass losses. Surface lowering, thickness loss and the resulting reduction in driving stress and flow, however, increasingly replace processes of tongue retreat with processes of downwasting, disintegration or even collapse of entire glaciers. Moreover, the thickness of most glaciers regularly observed for their mass balance is measured in (a few) tens of meters. From the measured mass losses and thickness reductions, it is evident that several network glaciers with important long-term observations may not survive for many more decades. A special challenge therefore consists in developing a strategy for ensuring the continuity of adequate mass balance observations under such extreme conditions (Zemp et al., 2009).

The volume 50 (50) of the Annals of Glaciology published in 2009 presents recent work from the International Workshop on Mass Balance Measurement and Modelling at Skeikampen, Norway, in 2008. Issues discussed also concern the uncertainty ranges of measured mass balances and the accessibility of information from individual stake/pit measurements in view of energy balance modelling. The ideal measurement accuracy for glacier mass balance is defined as 0.1 m w.e. with a threshold limit of 0.2 m w.e (IGOS 2007). This goal can only be reached by systematic comparison and – in cases of major deviations – adjustment of the direct glaciological with geodetic mass balances (e.g. Thibert et al., 2008; Cogley, 2009; Huss et al., 2009). A corresponding quality ranking may have to be introduced with respect to the internationally reported numbers. Access to point measurements relates to complex questions and may, at first, become possible only in a limited number of cases.

Completion of the present Glacier Mass Balance Bulletin was made possible through the cooperation of the National Correspondents to WGMS and the Principal Investigators of the various glaciers, as listed in Chapter 5. Thanks are due to Ursina Gloor and Dorothea Stumm for their assistance with data collection, quality control and editing of this issue, and to Susan Braun-Clarke for carefully editing the English. Funding is mainly through the WGMS Bridging Credit of the Swiss National Science Foundation and the Department of Geography at the University of Zurich with contributions by FAGS/ICSU, the Federal Office for the Environment (FOEN) and by the Cryospheric Commission of the Swiss Academy of Sciences.

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5 PRINCIPAL INVESTIGATORS AND NATIONAL CORRESPONDENTS

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